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Research paper

# Alterations in attentional processing in youth with misophonia: A phenotypical cross-comparison with anxiety patients

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ABSTRACT

*Background:* Misophonia is a complex condition characterized by extreme emotional distress in response to specific sounds or specific visual stimuli. Despite a growing body of clinical and neuroscientific literature, the etiology of this condition remains unclear. Hyperarousal, that is, a state of heightened alertness and disinhibition, as a core feature of misophonia is supported by behavioral and neuroimaging literature and might represent a viable clinical target for the development of both behavioral and pharmacological interventions. The aim of this study was to investigate how hyperarousal might be linked to neurocognitive processes associated with vigilance and stimulus discrimination in youth with misophonia.

*Methods:* We compared 72 children and adolescents with misophonia (13.74 ± 2.44 years) (64 % female) and 89 children and adolescents with anxiety (12.35 ± 2.57 years) (58.4 % female) on behavioral and signal detection performance of the immediate memory task (IMT). Anxiety patients were used as a clinical control group to distinguish attentional processes specific for misophonia.

*Results:* Both groups demonstrated similar behavioral performance, including response rate and reaction time. However, misophonia was associated with elevated stimulus discrimination (d prime), which in turn was positively correlated with the severity of misophonia trigger reports.

*Conclusions:* Our findings are in line with previous cognitive and neuroimaging studies, and support an arousal-based model of misophonia, where individuals with misophonia experience a state of heightened vigilance, being more aware of stimuli in the environment. Our findings provide a neurocognitive basis for future study of neurochemical imaging that might further progress towards clinical targets.

## 1. Introduction

Misophonia is a poorly characterized yet debilitating illness characterized by extreme physiological, behavioral, and emotional reactions to specific sounds or visual stimuli (Cervin et al., 2023; Guzick et al., 2023; Jager et al., 2020). Trigger sounds are common sounds generated by other people during processes such as breathing, eating, or moving. These can include chewing, rasping or rattling of breath during breathing, clicking or tapping of fingers/joints, or interaction with mechanical objects that results in clicking, tapping, crunching sounds. The etiology of misophonia is poorly understood, however, the presentation is distinct from sensory conditions such as hyperacusis and phonophobia, which refer to sound level specific reactions and general fear responses respectively (Jager et al., 2020; Swedo et al., 2022). Misophonia often causes great distress to affected individuals and their families, with detrimental effects on quality of life and everyday functioning (Guzick et al., 2023). Misophonia typically onset during childhood or adolescence, but the mechanisms of its prodromal development and subsequent maintenance remain unknown. This adds to the confusion of how to best classify misophonia and making it unclear if this is best

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conceptualized as a psychological, neurological, or audiological condition. Accordingly, no pharmacological intervention is currently available to alleviate misophonia symptoms, and psychological treatments (e.g., cognitive-behavioral therapy [CBT]) are just beginning to emerge (Rappoldt et al., 2023). A better understanding of the key neurocognitive mechanisms involved in the onset and maintenance of misophonia is needed to identify clinical targets and to design and personalize interventions. Our aim in this study is to identify affected elements of attentional processing that are distinct to misophonia in a youth population.

Early studies of misophonia identified physiological responses such as heightened galvanic skin response (Edelstein et al., 2013), increased heart rate (Grossini et al., 2022), and muscular tension (Dozier et al., 2020) in response to certain auditory stimuli. These responses imply the possibility of elevated vigilance of the autonomic nervous system. Changes to vigilance, even when temporary or contextual, can impair cognitive functions across neuropsychological domains, including working memory (Berryman et al., 2017; MacNamara et al., 2019), set-shifting (Coifman et al., 2018), and cognitive control (Crane et al., 2016), which in turn can result in impaired social functioning and poor quality of life (Bar-Tal et al., 2013; Guzick et al., 2023; Rinaldi et al., 2022). In misophonia, heightened vigilance in anticipation of misophonic triggers would at least partially explain the altered sensitivity to sound stimuli, as well as the mood disturbances typical for the condition (Cassiello-Robbins et al., 2020; Schröder et al., 2013; Siepsiak et al., 2022).

Neuroimaging studies support the notion of a heightened state of vigilance in misophonia, pointing to altered attribution of processing resources within the salience network (Kumar et al., 2017; Schröder et al., 2019). Findings from multivariate functional imaging suggest that audio-visual misophonic trigger stimuli, but not generally aversive or neutral stimuli, may be associated with enhanced hemodynamic response in the insula, anterior cingulate cortex, and superior temporal cortex in individuals with misophonia relative to controls (Schröder et al., 2019). Moreover, these stimuli elicited intense feelings of disgust, anger, and sadness, emphasizing the distorted salience these stimuli hold in affected individuals. Individuals with misophonia, but not controls, have also demonstrated elevated heart rate during both misophonic and generally aversive conditions (Edelstein et al., 2013; Schröder et al., 2019). What the combination of these findings imply is that individuals affected by misophonia exhibit a heightened level of arousal that lowers the detection threshold for potentially aversive stimuli. This form of systemic biasing towards certain sensory stimuli can be observed by examining response inhibition with a modified Stroop task, where higher levels of vigilance make it easier for sensory stimuli to override cognitive processes (Daniels et al., 2020). In this instance, misophonic trigger sounds, but not universally unpleasant sounds, increased the Stroop effect in participants with higher trait anxiety (Daniels et al., 2020).

The effect of symptom provocation on attentive processes is a key element in the hypervigilance/arousal model of misophonia etiology. However, the functional imaging data to date only present a macro-level picture of how this aspect of misophonia is organized. This was addressed by Frank et al. (2020) using a modified version of the Attention Network Task (ANT) designed to assess neurocognitive processes associated with three independent attention networks: alerting attention, orienting attention, and executive attention (Frank et al., 2020). Importantly, each of these attentional networks overlap with the circuits described by Schröder et al. (2019) and Kumar et al. (2017). The authors identified differences between misophonia patients and controls in alerting attention while orienting and executive attention were not different between the groups. Alerting attention is related to neural activity in a network of frontal and parietal regions, which exhibits control over the initiation and maintenance of an attentive response (Posner and Petersen, 1990). To address the importance of sound processing on attention components, the task had been modified to include misophonic sound presentations in certain blocks. Interestingly, there was no interaction with the sound condition, suggesting that the alterations to alerting attention exist as part of broader alterations in attentional processing, which is in line with previous functional imaging studies suggesting that misophonia is associated with an altered functional state characterized by heightened levels of arousal.

For understanding misophonia etiology, it is important to break down the manner in which hypervigilance impacts different cognitive domains and computational processes. In the ANT study, individuals with misophonia did not display difficulties related to orienting attention (Frank et al., 2020), a finding presumably at odds with behavioral traits observed in misophonia, for example, escape/avoidance behavior (Guzick et al., 2023), and strategic delaying of responses (Eijsker et al., 2019). A promising avenue to further explore the computational properties of attention in misophonia is to use the Immediate Memory Task (IMT). The IMT was adapted from the Continuous Performance Task (CPT (Klee and Garfinkel, 1983), a task used to measure discriminability and impulsive regulation by contrasting correct detections with commission errors (responses to non-target stimuli (Dougherty et al., 2003)). In the IMT, the goal is to select if a cue and target stimulus (5 number sequence) match or not. Non-matching trials can be commission errors (1 digit different in the target stimulus), random errors (neither cue nor target match), or filler errors (cue and target are two halves of a ten-digit sequence). See Fig. 1 for a description of the task. This design distinguishes random and/or impulsive incorrect responses from incorrect anticipatory responses (commission errors), providing a more nuanced approach to estimating both response sensitivity and response bias (e.g., the cognitive strategy for response making) (Dougherty et al., 2000). Signal detection theory can be used to resolve the degree of response sensitivity and bias during the IMT (Dougherty et al., 2003, 2000; Pastore and Scheirer, 1974) and might help to shed light upon cognitive processes related to orienting and executive attention in misophonia (Frank et al., 2020).

Modeling of reaction times (RT) during the IMT is another approach that can help explain variability in the allocation of resources to attentive processes. In particular, ex-Gaussian modeling of RTs, which accounts for the non-parametric distribution of timings, has been shown to be a sensitive indicator of fluctuating attention (Schumacher et al., 2019) (Schumacher et al., 2019). The ex-gaussian distribution has three components: mu, sigma, and tau, which represent the mean, standard deviation, and exponent respectively. Studies in attention deficit hyperactivity disorder (ADHD) (Galloway-Long and Huang-Pollock, 2018), aging (Schumacher et al., 2019), and working memory (Shahar et al., 2014) have helped to provide a theoretical description of the ex-gaussian parameters. The gaussian parameters of mu and sigma relate to the general accuracy of performance, whereas the tau parameter relate to the allocation of resources and maintenance of task-appropriate attention (Ratcliff, 1979). Previous work has identified that dysfunctional aging such as in dementia (Schumacher et al., 2019), and developmental difficulties with hyperactivity such as in ADHD (Galloway-Long and Huang-Pollock, 2018) are associated with larger tau components in RT distributions, indicating less precise allocation of attentional resources.

The aim of the present study is to explore attentional processes in children and adolescents with misophonia. To distinguish processes specific for misophonia, we will include a clinical comparison group of youth with anxiety disorders, another condition characterized by alterations in attentional processing (Pacheco-Unguetti et al., 2010), making it possible to distinguish mechanisms specific for misophonia. Based on the arousal model of misophonia described above, we hypothesize that the ex-gaussian tau property of RT distributions might be a strong computational marker of misophonia pathology. We further hypothesize that if misophonia patients exhibit a functional difference that renders them in a hypervigilant state, they will have greater response sensitivity and a more liberal response bias. As an exploratory measure, we will examine response rates for different cue conditions and

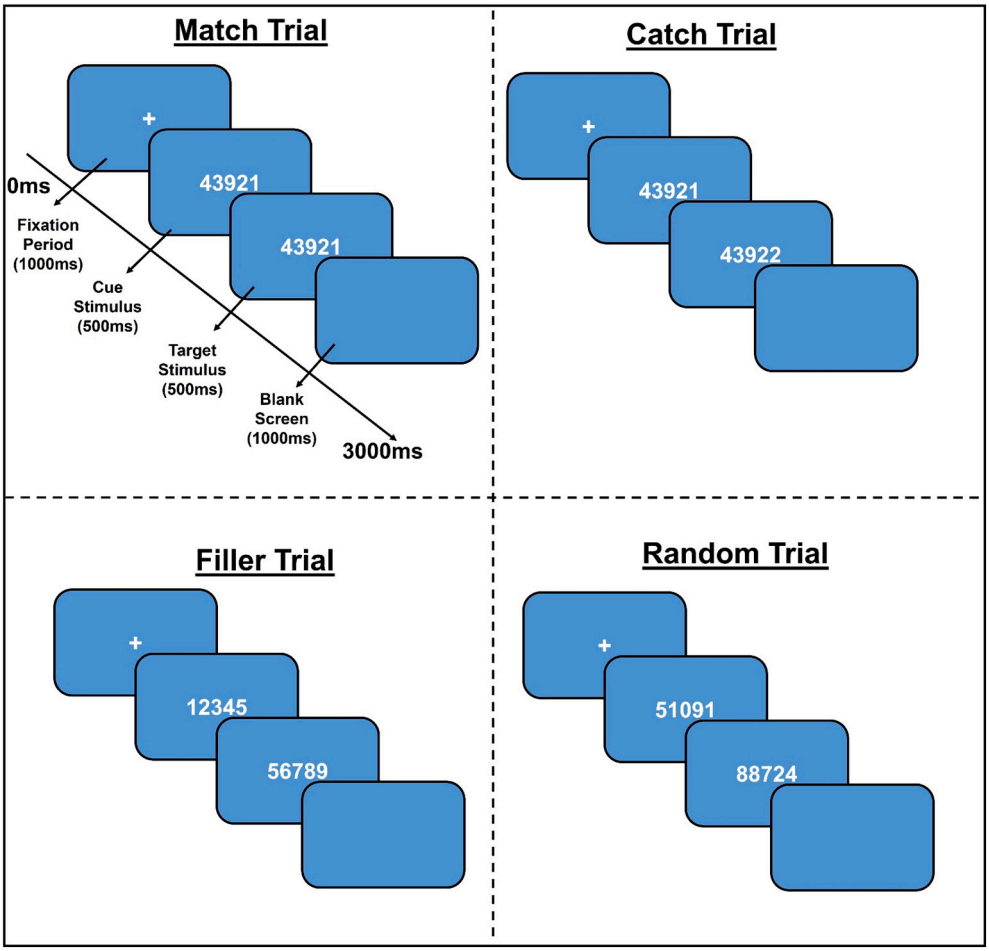


**Fig. 1.** Schematic depiction of the IMT paradigm.

the ex-Gaussian distribution of reaction times as a measure the computational and biological contributions to decision making.

## 2. Methods

### 2.1. Participants

We drew data from a broader project that included 102 children and adolescents (13.69 ± 2.51 years) (67.6 % female) who met the proposed diagnostic criteria for Misophonia and 94 children and adolescents with anxiety disorders (12.41 ± 2.55 years) (57.4 % female). The complete demographic profiles of these samples have been previously described (Guzick et al., 2023). Using the completion of the online IMT task as an entry requirement for the present study, 72 misophonia (13.74 ± 2.44 years) (64 % female) and 89 anxiety patients (12.35 ± 2.57 years) (58.4 % female) were included in the IMT analysis.

### 2.2. Immediate memory task

In the IMT, we used 5-digit sequences of numbers as the cue and target stimuli (see Fig. 1). The objective of the task is to make a response using one of the two button options provided to indicate if the target stimulus was identical to the cue stimulus. Participants were presented with a fixation cross (1000 ms) followed by the cue stimulus (500 ms) and then the target stimulus (500 ms). After the target stimulus had disappeared, participants were presented with a blank screen (1000 ms). At the presentation of the target stimulus, participants could respond as to whether it matched (1) or not (0) the cue stimulus. The IMT consisted of 4 trial types: 1) Match: cue and target arrays were identical; 2) Catch: target array was different from the cue array by 1 digit (e.g., Cue = 46,781 and Target = 46,782); 3) Random: target array and cue array were completely different (e.g., Cue = 16,093 and Target = 27,515); 4) Filler: cue and target array were two parts of a ten digit sequence (e.g., Cue = 12,345 and Target = 56,789). Trials were presented in a random order for each participant with an inter-stimulus interval of 500 ms preceding the end of the response period and the start of the next fixation period. Each condition consisted of $N = 25$ trials for a total of $N = 100$ trials. A brief run of 11 practice trials were presented beforehand to reduce random error. The total experiment time was 5 min and 55 s. The experiment was created using Gorilla Experiment Builder (Anwyl-Irvine et al., 2021, 2018).

### 2.3. Clinical and behavioral measures

To evaluate the influence of self-reported symptom domains on task performance, we used the following clinical ratings to characterize: 1) *Misophonia*: the Amsterdam Misophonia Scale (A-MISO-S) (Cervin et al., 2023; Schröder et al., 2013), the Misophonia Inventory of Sound Triggers (MIST), a trigger list that was developed for this study, which was summed to create a total trigger count, the Misophonia Assessment Questionnaire (MAQ) (Cervin et al., 2023; Johnson and Dozier, 2013), and the Glasgow Sensory Questionnaire (GSQ) (Robertson and Simmons, 2013); 2) *Anxiety:* the Multidimensional Anxiety Scale for Children (MASC) (March, 1997), the Behavioral Inhibition-Activation Scales (BIS/BAS) (Carver and White, 1994); and 3) *Other emotional symptoms and mechanisms*: Child and Adolescent Symptom Inventory (CASI-5) (Gadow and Sprafkin, 2013), Cognitive Emotion Regulation Questionnaire (CERQ) (Garnefski et al., 2001), Youth Self Report (YSR)

(Achenbach, 1995).

### 2.4. Pre-processing and feature extraction

#### 2.4.1. Response accuracy and signal detection

The primary analysis of the IMT task involved extracting response accuracy and reaction times per condition. Response accuracy was used to the hit rate and false alarm rate that act as the base for estimating signal detection measures: Sensitivity (d prime, d′), bias (c).

To estimate these measures, we first calculated the hit and false alarm rates for the IMT. Hit rate (HR) refers to the ratio of correct matches in the "Match" condition (*hit*) to the total number of "Match" trials (N). Similarly, the false alarm rate (FR) refers to the number of commission errors made relative to the total number of trials in the catch trials.

$$HR = \frac{((\sum \text{hit}) + 0.5)}{N + 1}$$

$$FR = \frac{((\sum \text{false alarm}) + 0.5)}{N + 1}$$

d′ was then measured as the difference between the normalized HR and FR, where normalization was performed by estimating the percent point function. C was estimated as the product of −0.5 times the sum of the normalized HR and FR.

$$d' = Z(HR) - Z(FR)$$

$$c = -0.5*(Z(HR) + Z(FR))$$

#### 2.4.2. Reaction times

We modeled the ex-Gaussian reaction times for the IMT task using the DISTRIB (Lacouture and Cousineau, 2008) toolbox for Matlab. DISTRIB estimates the ex-Gaussian function through the multiplication of the cumulative density of the Gaussian function for the reaction time data by an exponential function. The fit is optimized by using a parameter search algorithm to maximize the representation of the data in the distribution (Lacouture and Cousineau, 2008). Ex-Gaussian parameters were estimated using all correct trials with a latency >200 ms (collapsing across conditions).

### 2.5. Statistics

We evaluated the effect of misophonia pathology on our data using a two-part strategy. In part one; standard comparisons of the behavioral data were performed. IMT response accuracy by trial type were analyzed using repeated measures analysis of variance (ANOVA). Signal detection measures and ex-gaussian parameters were compared between groups using independent samples *t*-tests. Correlations between significant experimental measures and clinical ratings were estimated using bootstrapped Pearson's r. To perform correlations, the database was split and the analyses were run for misophonia and anxiety patients separately. Correlations were Bonferonni corrected to adjust for multiple comparisons within measurement (Misophonia, Anxiety, and Other emotional symptoms/mechanisms measures) families (Misophonia [$p = .008$], Anxiety [$p < .008$], *Other emotional symptoms/mechanisms* [$p < .0125$]). In part two, we measured the contributions of age and biological sex to the variance within the data using a three-block linear regression. In block one the experimental group was used as the only coefficient. In block two age was added, and in block three biological sex was added. The contributions of additional coefficients were evaluated using the F change statistic. Sex distributions were compared between the groups using the chi squared test of independence.

## 3. Results

### 3.1. IMT performance

Our ANOVA showed a significant main effect of condition ($F = 124.64$, $df = 3$, $p < .001$, $\eta^2 = 0.44$) but not group ($F = 2.06$, $df = 1$, $p < .15$, $\eta^2 = 0.01$) or group*condition ($F = 0.74$, $df = 3$, $p < .53$, $\eta^2 = 0.005$). IMT task performance was associated with reduced accuracy during catch trials relative to other conditions, but performance was not affected by group membership. See Table 1 and (Fig. 2).

### 3.2. Signal detection

d′ was statistically significantly greater in Misophonia patients compared to anxiety patients ($t = -2.12$, $df = 159$, $p = .036$, $d = -0.336$, CI = −0.65 to −0.02), indicating a higher rate of "hits" to "false alarms." c was not significantly different between groups ($t = 0.47$, $df = 159$, $p = .64$, $d = 0.07$, CI = −0.24 to 0.38). Means are displayed in Table 2. In Misophonia patients, d′ was significantly correlated with the MIST-C ($r = 0.33$, $p = .005$) and the CERQ total score ($r = 0.31$, $p = .008$). No other clinical variables were significantly associated with d′ or c scores (Fig. 3).

### 3.3. Reaction times

Mu ($t = -0.46$, $df = 159$, $p = .65$, $d = -0.07$, CI = −0.38 to 0.24), sigma ($t = 0.49$, $df = 159$, $p = .63$, $d = 0.08$, CI = −0.23 to 0.39), and tau ($t = -1.09$, $df = 159$, $p = .27$, $d = -0.17$, CI = −0.48 to 0.14) parameters were not significantly different between groups. Means are displayed in Table 3 and (Fig. 4).

### 3.4. Contributions of developmental biology

After identifying that signal detection was significantly different between the groups, we used linear regression to model the contributions of age and biological sex. In the baseline model, group was a significant predictor of d′ ($R^2 = 0.02$, $F = 4.49$, $p = .036$), where group had a beta value of $\beta = 0.16$ ($p = .036$). The addition of age ($\beta = 0.335$, $p < .001$) significantly altered the model ($R^2$ change = 0.105, F change = 19.13, $p \leq 0.001$), reducing the beta value for group to $\beta = 0.079$ ($p = .302$), implying a positive influence of age on d′ present in both groups. Conversely the addition of sex (Male B = −0.1, $p = 55$, Female $\beta = -0.1$, $p = .52$) did not present any additional alterations to the model ($R^2$ change = 0.002, F change = 0.207, $p = .81$).

### 3.5. Sex distribution

Sex distributions were not significantly different between the groups ($\chi^2 = 1.7$, $df = 2$, $p = .043$). In the anxiety group $N = 30$ reported male, $N = 53$ reported female, and $N = 6$ reported not identifying with either. In the misophonia group $N = 22$ reported male, $N = 48$ reported female, and N = 2 reported not identifying with either.

## 4. Discussion

Currently the diagnosis and treatment of misophonia is suffering due to a lack of understanding of its underlying neurobiological mechanisms. In this study, we used the IMT to investigate neurocognitive properties of attention in misophonia that have previously been linked to arousal (Frank et al., 2020). Using a two-step analysis of the IMT, we first demonstrated differences in response sensitivity (dprime, d′) between the groups, indicating heightened stimulus discriminability in misophonia patients relative to anxiety patients. In the second stage of our analysis we used linear modeling to identify the contributions of age and biological sex to the variance in d′. Linear modeling demonstrated a moderate contribution of age, but not biological sex, which in turn

**Table 1**
Comparison of IMT behavioral Performance (Anxiety group is used as the point of reference).

| | | Mean difference | 95% CI for mean difference | | SE | *t* | Cohen's D | 95% CI for Cohen's D | | *p* |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Lower | Upper | | | | Lower | Upper | |
| Match | Catch | 23.29 | 18.73 | 27.85 | 1.72 | 13.54 | 1.23 | 0.93 | 1.53 | <0.001 |
| | Filler | −4.45 | −9.01 | 0.11 | 1.72 | −2.59 | −0.24 | −0.48 | 0.01 | 0.06 |
| | Distractor | −5.81 | −10.36 | −1.25 | 1.72 | −3.37 | −0.31 | −0.56 | −0.06 | 0.005 |
| Catch | Filler | −27.74 | −32.29 | −23.18 | 1.72 | −16.12 | −1.46 | −1.79 | −1.14 | <0.001 |
| | Distractor | −29.1 | −33.65 | −24.53 | 1.72 | −16.91 | −1.54 | −1.87 | −1.2 | <0.001 |
| Filler | Distractor | −1.36 | −5.92 | 3.2 | 1.72 | −0.79 | −0.07 | −0.31 | 0.17 | 1 |

Note - P value and CI's are adjusted for comparing a family of 6 estimates using the Bonferroni method.

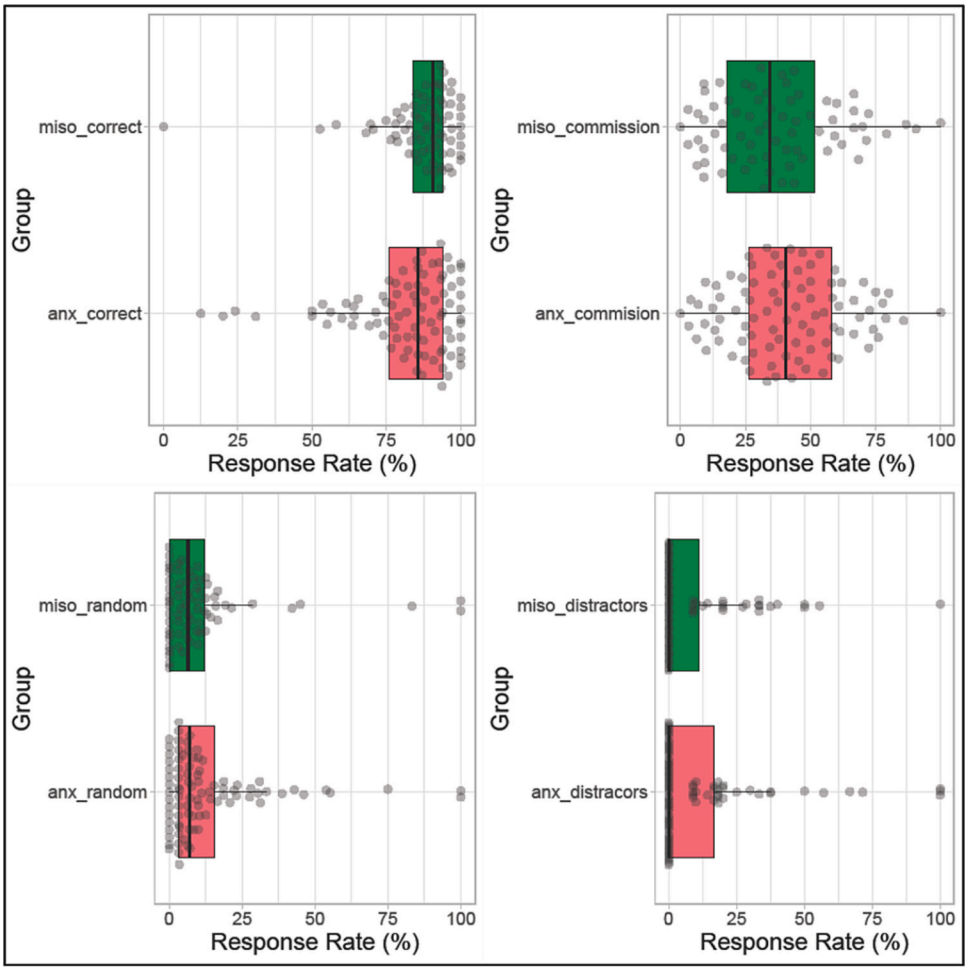


**Fig. 2.** Response rates per IMT trial type. Response rate refers to the percentage of correct responses for a given trial type.

**Table 2**
Comparison of signal detection theory measures between groups (across all trial types). 0 = Anxiety, 1 = Misophonia.

| Measure | Group | N | Mean | SD | SE | Coefficient of variation |
|---|---|---|---|---|---|---|
| D prime | Anxiety (0) | 89 | 1.24 | 0.95 | 0.1 | 0.76 |
| | Misophonia (1) | 72 | 1.56 | 0.95 | 0.11 | 0.61 |
| Bias | Anxiety (0) | 89 | −0.37 | 0.44 | 0.05 | −1.18 |
| | Misophonia (1) | 72 | −0.4 | 0.39 | 0.05 | −0.95 |

reduced the group factor. The effect of age on d′ could suggest that there is the possibility of misophonia specific differences in attention during early development but that these become less substantial in line with natural cognitive development. Conversely, poorer attention in early age might simply be related to less developed executive functions. Further work is needed to elucidate the trajectory of misophonia specific differences in attention.

Existing work in the neuroscientific sphere has largely sought to characterize the functional architecture but has not yet identified a mechanism by which pathology leads to the core symptoms of the disorder. Current hypotheses point to a state of hyper-arousal influencing resource allocation during sensory processing (Daniels et al., 2020; Edelstein et al., 2013; Frank et al., 2020; Neacsiu et al., 2022; Schröder et al., 2019). Because both misophonia and anxiety disorders are characterized by attentional impairments, and a healthy control group was not included in our design, we performed follow-up analysis of the relationship of d′ to misophonic trigger information. We observed a positive correlation between total sound triggers and d′ in the

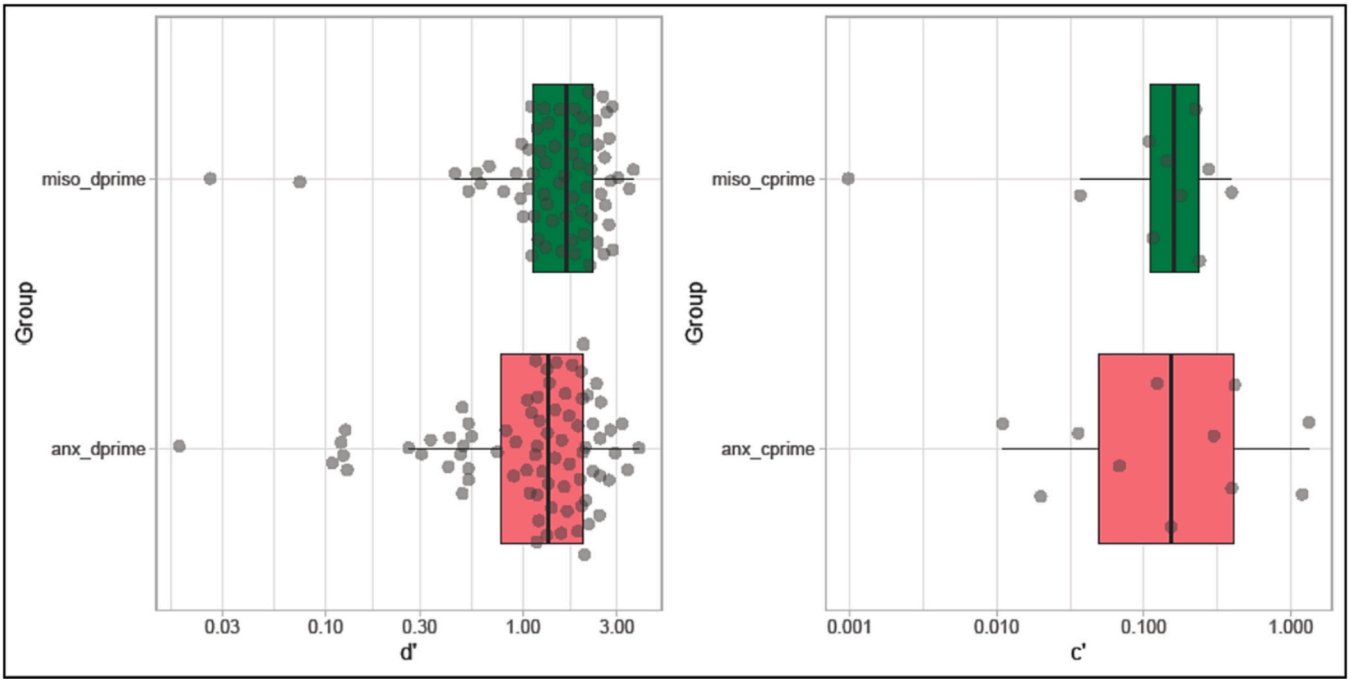


**Fig. 3.** Comparison of signal detection theory measures between groups (across all trial types).

**Table 3**
Comparison of ex-Gaussian parameters between groups. 0 = Anxiety, 1 = Misophonia.

| Measure | Group | N | Mean | SD | SE | Coefficient of variation |
|---|---|---|---|---|---|---|
| Mu | Anxiety (0) | 89 | 414.18 | 288.53 | 30.58 | 0.69 |
| | Misophonia (1) | 72 | 433.51 | 237.78 | 28.02 | 0.55 |
| Sigma | Anxiety (0) | 89 | 86.15 | 75.99 | 8.06 | 0.88 |
| | Misophonia (1) | 72 | 80.5 | 68.73 | 8.1 | 0.85 |
| Tau | Anxiety (0) | 89 | 114.12 | 91.88 | 9.74 | 0.81 |
| | Misophonia (1) | 72 | 129.34 | 81.74 | 9.63 | 0.63 |

misophonia sample. This finding is in line with previous accounts of increased alerting of attention in misophonia patients during the ANT (Frank et al., 2020) and might imply that perceptual and attentional systems in misophonia are tuned to be more alert for the purpose of identifying and avoiding trigger sounds. However, for the purpose of identifying this earlier in development this hypothesis should be contrasted with the alternate hypothesis that heightened alertness precedes misophonia development and represents a potential risk factor. More specific developmental research will be necessary to determine the nature of this hypothesis. Accordingly, behavioral performance in terms of response accuracy and reaction times were not significantly different from youth with anxiety disorders, implying that pathology in misophonia might differentially affect the systems for arousal and cognitive function. This would track with previous reports implicating hypervigilance and anticipatory anxiety as core to the clinical presentation of misophonia in youth and adults (Jager et al., 2020; Swedo et al., 2022). In our study the ex-gaussian distribution was used as it has previously been linked to learning effects within a task (Schmiedek et al., 2007). The shape of the exponential distribution has been linked to resource allocation and might be affected by arousal such as seen in attention deficit hyperactivity disorder (ADHD) (Hwang Gu et al., 2013). In our results the lack of significant differences in the ex-gaussian parameters suggests that the mechanism of resource allocation for task learning is not different in anxiety or misophonia.

The lack of significant differences between misophonia and anxiety groups on other IMT performance outcomes may indicate that there are non-specific disruptions in other attentional processes across youth with both misophonia and anxiety disorders (e.g. (Najmi et al., 2012)), as youth with anxiety disorders have been shown to experience deficits in other attentional domains (Sylvester et al., 2016). The lack of a non-psychiatric comparison groups does not enable this study to make these conclusions definitively, though given prior work on this topic, it is a possibility that youth with misophonia might also experience impairments in these attentional domains, reflecting transdiagnostic deficits associated with psychopathology more broadly.

## 5. Limitations and future directions

The present study has several limitations. First is the lack of a healthy control group. In our study it is difficult to discern the extent to which the lack of distinctions between misophonia and anxiety constitute a lack of behavioral deficits. Second, our test uses numeric stimuli for the matching conditions, restricting our ability to draw conclusions about broader perceptual processes. This experiment was conducted across multiple years coinciding with the COVID-19 pandemic. As such, certain elements of the experiment were limited to what could be conducted virtually. Due to the strict requirements for auditory processing studies, such as volume control and sound presentation, a visual numeric format of the experiment was used as it could be easily recreated on a variety of monitors without affecting task performance. Future work should address this by implementing a multivariate format of the experiment, including an auditory discrimination task. Third, although the IMT provides a means of testing the properties of decision-making and how they are affected by arousal, it does not describe detailed neurophysiological processes constructing the functional architecture in which this occurs. In future work it is critical to address how properties of attention are related to the parameters of excitation and inhibition balance that can be described using electroencephalography. Finally, the relationship between d′ and misophonic trigger information warrants further investigation, as this might indicate a first step for exploring neurocognitive assessments as part of clinical practice for misophonia. In our study it is a

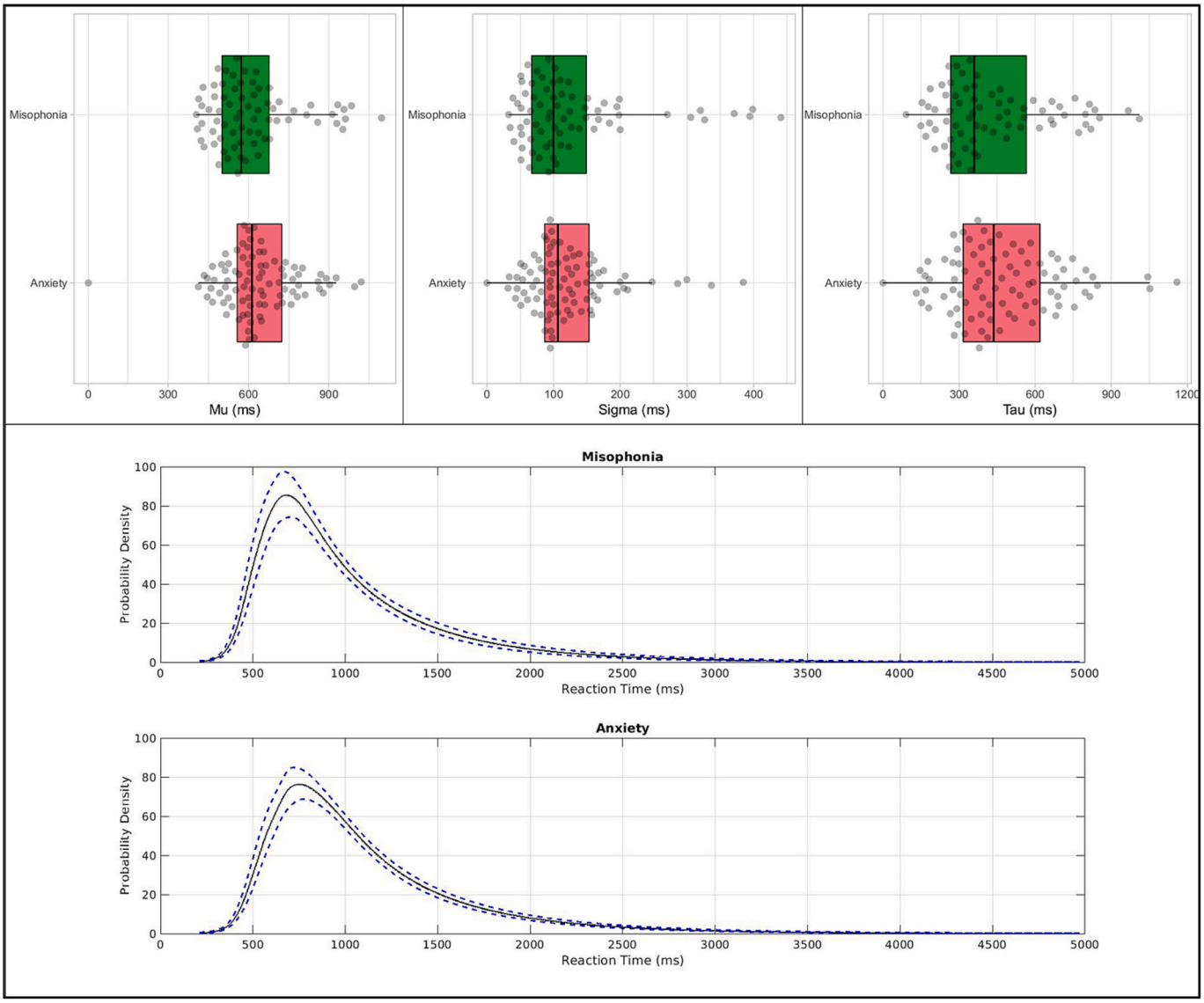


**Fig. 4.** (Top) Visual comparison of ex-gaussian parameter distributions between groups. (Bottom) Comparison of probability density functions for fitted ex-gaussian estimates of reaction time data.

possibility that our analyses of the IMT outputs are tapping into practice effects of people with misophonia. These individuals are used to being alert to stimuli indicating that a trigger might occur, therefore putting them in a state where it is natural to pick up on subtle differences in stimuli that others might not notice. Ultimately the etiology of misophonia is unknown and future research must address practical designs in the tests use to study properties such as arousal and hypervigilance so that causal effects can be identified.

## 6. Conclusions

Alterations in cognitive systems, through which attentional resources are directed towards the identification and avoidance of trigger sounds, may be an avenue for future work to refine neurocognitive markers for misophonia in children and adults. Approaches based on signal detection theory provide a complimentary perspective to existing functional imaging studies by summarizing the computational properties of targeted systems. In this study, we observed a dimensional relationship between misophonic trigger load and response sensitivity. However, it still remains unclear how bottom-up sensory gating processes might interact with higher-order cognitive processes associated with the complex patterns of behavior (Guzick et al., 2023) and aberrant neural connectivity (Neacsiu et al., 2022) seen in misophonia. Future research should examine the exact influence of auditory stimuli on attentional processing and how interventions can integrate findings from experimental research to improve effects of treatment.

## Author statement

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## Declaration of competing interest

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