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A neuropsychological study of misophonia

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ABSTRACT

Background and objectives: Misophonia is a recently identified condition characterized by negative emotional responsivity to certain types of sounds. Although progress has been made in understanding of neuronal, psychophysiological, and psychopathological mechanisms, important gaps in research remain, particularly insight into cognitive function. Accordingly, we conducted the first neuropsychological examination of misophonia, including clinical, diagnostic, and functional correlates.

Methods: A misophonia group (n = 32) and a control group (n = 64) were screened for comorbidities using a formal semi-structured interview and completed a comprehensive neuropsychological battery and self-report measures of depression, anxiety, stress, impulsivity, and functional impairment.

Results: The misophonia group significantly underperformed the control group on only 2 neuropsychological outcomes involving verbal memory retrieval. Subscales of the Misophonia Questionaaire (MQ) were inversely correlated only with measures of attention. The misophonia group reported significantly higher anxiety symptoms, behavioral impulsivity, and functional impairments, and had numerically higher rates of ADHD and OCD.

Limitations: To facilitate comparability, in lieu of a formal diagnostic algorithm for misophonia, we used a commonly used empirical definition for group allocation that has been utilized in numerous previous studies.

Conclusions: Misophonia was associated with a reduction in performance on a minority of cognitive tasks and a modest increase in some psychological symptoms and comorbid conditions. Correlational data suggest that difficulties with attention regulation and impulsivity may play a role in misophonia, albeit attention functions were intact. Results should be interpreted with caution given the variability in diagnostic definitions, and more research is needed to understand cognitive functioning under 'cold' conditions in misophonia.

Misophonia is characterized by strong aversion to a range of primarily human-produced sounds, including those related to eating (e.g., chewing, swallowing, slurping), nasal sounds (e.g., sniffing and inhaling), rustling sounds (e.g., paper, plastic), and repetitive tapping (e.g., pen clicking, foot tapping; Swedo et al., 2022; Swedo et al., 1989), although misophonia triggers may also include sounds produced by animals as well as some forms of visual movement, often termed misokinesia (Hansen, Leber, & Saygin, 2021). Despite the variability in the type of trigger stimuli, misophonic responses to triggers involve a similar pattern of aversive physiological reactions and intense negative emotions including irritability, anxiety, and extreme anger (Edelstein, Brang, Rouw, & Ramachandran, 2013; Ferrer-Torres & Giménez-Llort, 2022). These may be accompanied by an impulsive behavioral response (Potgieter et al., 2019) such as verbal aggression (Schroder, Vulink, & Denys, 2013; Swedo et al., 2022); or by avoidance of the misophonic trigger (Potgieter et al., 2019). Notably, the misophonic response may include physical aggression, although research indicates that these responses are rather rare and more common in youth (Swedo et al., 2022).

In the two decades since the term misophonia was first coined by Jastreboff and Jastreboff (2001), researchers have reported that misophonia is likely associated with rigidity and with deficient emotion regulation and impulse control (Cassiello-Robbins et al., 2020; Guetta, Cassiello-Robbins, Trumbull, Anand, & Rosenthal, 2022), and that features of the stimuli such as volume are less important than the person's attribution of meaning to the action and sound, particularly the perception that the action and the sound produced are contextually inappropriate (Cowan, Marks, & Pinto, 2022). However, research on misophonia suffers from inconsistency across studies regarding core features, mechanisms, comorbidity, and prevalence; in part because formal diagnostic criteria for misophonia have not yet been established. For example, published estimates of the prevalence of misophonia range as widely as 5%–18% (Jakubovski, Müller, Kley, de Zwaan, &

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Müller-Vahl, 2022; Kılıç, Öz, Avanoğlu, & Aksoy, 2021; Vitoratou et al., 2023). As such, more research is needed to understand multiple aspects of misophonia (Cowan et al., 2022; Frank, Roszyk, Hurley, & McKay, 2020).

Evidence suggests that the misophonic reaction involves fight-or-flight sympathetic nervous system activation, and hyperactivity in the limbic system, particularly the amygdala (Edelstein et al., 2013; Kumar et al., 2017). Indeed, the intense aversiveness of the misophonic sounds and associated emotional response often leads to broad avoidance of situations in which the triggering sounds are likely to be encountered, such as dinner with family and going out to restaurants or movie theaters, or excessively using headphones to avoid trigger sounds. Such behaviors may significantly impair family and social functioning (Potgieter et al., 2019; Schroder et al., 2013).

Initially, Jastreboff and Jastreboff (2014) suggested that misophonia is not associated with psychopathology. However, in light of accumulating research, it is becoming increasingly clear that the condition is associated with elevated anxiety and stress symptoms and increased comorbidity with DSM disorders including anxiety disorders, mood disorders, personality disorders, obsessive compulsive-related disorders, post-traumatic stress disorder (PTSD), autism spectrum disorder, and attention deficit hyperactivity disorder (ADHD; Erfanian, Kartsonaki, & Keshavarz, 2019; Potgieter et al., 2019; Swedo et al., 2022). Although the lack of formal diagnostic criteria for misophonia precludes reliably characterizing comorbidity, it is clear from studies that use a range of criteria that misophonia frequently co-occurs with other clinically significant psychological symptoms and disorders. For example, some studies report that more than half of their misophonia sample met criteria for obsessive-compulsive personality disorder (OCPD, 54.4%; Schroder et al., 2013) which was considered by the authors as a risk factor for misophonia. They also speculated that ADHD (4.8%) may be related to misophonia due to distractibility and attentional shifts between visual and auditory cues (Schroder et al., 2013). Other studies found elevated comorbidity with OCD (15%), PTSD (15%) MDD (10%; Erfanian et al., 2019), and anxiety disorders (33%; Cassiello-Robbins et al., 2021).

1. Cognitive function in misophonia

Very little is known about cognitive functioning in misophonia, as few studies have been published to date (Daniels, Rodriguez, & Zabelina, 2020; Eijsker, Schroder, Smit, van Wingen, & Denys, 2019; Frank et al., 2020). However, in examining cognitive functioning in misophonia, it is important to recognize that the misophonic reactions and responses that may affect cognitive functioning occur in specific contexts. To that end it is useful to distinguish between 'cold' cognitive functioning, which occurs under emotionally neutral conditions; and 'hot' cognitive functioning, which occurs in response to emotionally charged conditions or stimuli. In a study of 'hot' cognitive functioning in misophonia using the Stroop paradigm, Daniels et al. (2020) found a larger Stroop effect among misophonia participants when continuous misophonic trigger sounds were played. Similarly, attention-related task performance was worse during misophonic provocation (Daniels et al., 2020; Eijsker et al., 2019; Frank et al., 2020; Simner, Koursarou, Rinaldi, & Ward, 2021). Another study that used a dichotic listening task reported that individuals with misophonia were significantly less accurate in identifying sentences while listening to misophonia trigger sounds (da Silva & Sanchez, 2019).

To our knowledge only two studies have examined 'cold' cognitive functioning in misophonia (i.e., cognitive functioning in the absence of misophonic provocation), neither of which found any performance difference between misophonia and control samples. Simner et al. (2021) found no differences in visual attention performance on an embedded figures attention task. Similarly, no misophonia-related deficits were observed on the Stop Signal Task, a measure of inhibitory functioning, when administered without misophonic provocation (Eijsker et al., 2019). Given the limited research to date in this area, the aim of the present study was to conduct a neuropsychological examination of misophonia, focusing on cold cognitive functioning. However, the absence of information about cold cognitive functioning in misophonia makes it difficult to draw clear directional hypotheses, particularly given that misophonia may not disrupt cognition outside the context of responding to provocation, and so any cognitive deficits may be observed primarily during exposure to misophonic trigger sounds. The aim of the present study is to provide comprehensive information regarding cognitive functioning without misophonic symptom provocation, clinical and diagnostic status, and their association in misophonia compared to a control group.

2. Methods

2.1. Participants

The final sample of ninety-six participants was drawn from a larger sample (N = 275) that was part of a large neuropsychological study at a university in the southwestern United States. Participants were recruited via flyers and recruitment emails distributed to students. Inclusion criteria included minimum age of 18, normal or corrected vision, and fluency in English. Exclusion criteria included age >65 or any history of major neurological conditions (e.g., epilepsy, brain injury). Participants were asked to avoid recreational drugs, prescription benzodiazepines, stimulant medications, or more than two alcoholic drinks in the 24 h prior to the experiment. The overall study sample consisted of 67 females (69.8%) and 29 males (30.2%) with an average age of 20.91 (SD = 2.87). The sample was ethnically diverse (See Table 1.). Because there are no formal diagnostic criteria for misophonia, we used the Misophonia Questionnaire (MQ; Wu, Lewin, Murphy, & Storch, 2014) to establish the misophonia and control groups. The MQ is among the most frequently used measures of misophonia (Rosenthal et al., 2021). The MQ guidelines suggest that a score of 7 or higher on the single item sound sensitivity severity scale is the optimal cutoff for identifying misophonia; this recommended cutoff has been used in numerous previous misophonia studies (e.g., Frank et al., 2020; Grossini et al., 2022; Guetta, Cassiello-Robbins, Trumbull, et al., 2022; McKay, Kim, Mancusi, Storch, & Spankovich, 2018; Schadegg, Clark, & Dixon, 2021; Zhou, Wu, & Storch, 2017). Following this recommendation, the misophonia group (n = 32) consisted of participants that scored ≥7 on the MQ sound sensitivity item, and the control sample (n = 64) included participants whose score was in the sample's lowest quartile on this item. Notably, as presented in the results section, the mean MQ subscale and total scores found in the present study were remarkably similar to scores found in previous studies, which facilitates comparability with the results of the present work. See Table 1 for demographic information.

2.2. Materials

2.2.1. Clinical measures

Mini-International Neuropsychiatric Interview 7.0 (MINI; Sheehan et al., 1998). The MINI is a valid and reliable semi-structured screening interview for primary DSM-5 disorders. The MINI 7.0 has demonstrated good psychometric properties (Sheehan et al., 1998).

Depression, Stress, Anxiety Scale-21 (DASS-21; Lovibond & Lovibond, 1995). The DASS-21 is a self-report questionnaire that assesses the severity of depression, anxiety, and stress symptoms in the past week. Each item is scored from 0 – "*did not apply to me at all*" to 3 – "*applied to me very much or most of the time*". The DASS-21 demonstrates very good psychometric properties (Lovibond & Lovibond, 1995), including in clinical (Clara, Cox, & Enns, 2001) and non-clinical samples (Sinclair et al., 2012). In the present study, good to excellent reliability was found (Cronbach's α = 0.92, 0.74, and 0.83, for the depression, anxiety, and stress subscales respectively).

Six Item-State Trait Anxiety Inventory (STAI-6; Marteau & Bekker,

Table 1
Demographic and clinical characteristics of control/misophonia groups.

	Misophonia (n = 32)	Control (n = 64)	F/X^2	Sig.
	Mean (SD)/%(n)			
Sex			2.47	0.11
Female	59.40% (19)	75.00% (48)		
Male	40.60% (13)	25.00% (16)		
Age	21.06 (2.45)	20.83 (3.07)	0.14	0.71
Education (years)	15.03 (1.12)	15.05 (1.83)	0.00	0.97
Ethnicity			2.47	0.48
Hispanic	28.10% (9)	35.90% (23)		
Non-Hispanic	62.50% (20)	57.80% (37)		
Other	6.30% (2)	6.30% (4)		
Race			5.05	0.41
American Indian/Alaskan Native	3.20% (1)	0% (0)		
Black American	12.90% (4)	15.60% (10)		
Asian American	16.10% (5)	6.30% (4)		
Native Hawaiian/Other Pacific Islander American	0.00% (0)	1.60% (1)		
White American	38.70% (12)	45.30% (29)		
Hispanic/Latino American	29.00% (9)	31.30% (20)		
MQ				
MQ-1 (trigger)	16.91 (7.13)	8.83 (6.19)	32.64	0.001
MQ-2 (reaction)	18.63 (8.86)	6.90 (5.88)	56.62	0.001
MQ-3 (severity)	9.09 (2.09)	2.25 (0.80)	321.40	<0.001
DASS-21				
DASS-21 Depression	4.48 (5.15)	3.36 (4.01)	1.32	0.25
DASS-21 Anxiety	4.58 (3.40)	2.90 (2.87)	4.39	0.01
DASS-21 Stress	5.35 (3.83)	3.80 (3.70)	3.62	0.06
I-7 Impulsivity	10.06 (3.32)	7.71 (3.25)	10.70	0.002
STAI-State	11.87 (4.40)	9.56 (3.02)	6.93	0.01

Note. MQ = Misophonia questionnaire; DASS-21 = Depression, Anxiety and Stress Scale-21; I-7 = Eysenck Impulsiveness and Venturesomeness Questionnaire; STAI-State = Six Item-State Trait Anxiety Inventory.

1992). The STAI-6 is a 6-item short-form self-report questionnaire adapted from the State-Trait Anxiety Inventory. The STAI-6 demonstrates good internal consistency in clinical and non-clinical samples (α = 0.82; Marteau & Bekker, 1992), as well as in the present study (α = 0.86).

The Eysenck Impulsiveness-Venturesomeness-Empathy Questionnaire (I-7; Eysenck, Pearson, Easting, & Allsopp, 1985) The I-7 is a 54-item self-report questionnaire that utilizes a "*yes or no*" format and that includes three subscales: Impulsiveness, Venturesomeness (i.e., risk taking), and Empathy. The measure demonstrates good psychometric properties in non-clinical samples including good internal consistency (α = 0.83; Eysenck et al., 1985). The outcome of interest in the present study was the I-7 Impulsiveness subscale score for which good internal consistency was found (α = 0.83).

Barkley Functional Impairment Scale (BFIS; Barkley, 2011). The 15-item BFIS assesses functional impairment in multiple domains of everyday life (e.g., school/work, social). The BFIS demonstrates good psychometric properties (Barkley, 2011). Due to a technical error only the first 10 BFIS items were administered. However, the BFIS manual indicates that the measure was developed to allow utilizing each individual item as a standalone functional construct and provides itemized norms. Thus, each item was used as a domain indicator and no summary score was computed.

Misophonia Questionnaire (MQ; Wu et al., 2014). The MQ consists of 17 items and comprises three subscales: MQ-1, assessing types and degree of sensitivity to trigger sounds; MQ-2, assessing the misophonic behavioral response; and MQ-3, assessing severity of sound sensitivity. A score of 7 or higher on the sound sensitivity subscale (MQ-3) indicates clinically significant misophonia. This cutoff has been used in several previous misophonia studies (e.g., Guetta, Cassiello-Robbins, Trumbull, et al., 2022; Schadegg et al., 2021). The MQ demonstrates good psychometric properties in non-clinical samples (Wu et al., 2014), as well as in the present study (α = 0.83).

2.2.2. Neuropsychological measures

2.2.2.1. Executive functions. The *Trail Making Test,* Part B (TMB; Delis, Kaplan, & Kramer, 2001). The TMB is a subtest of the Trail Making Test that assesses attentional set shifting in the graphomotor modality. Participants are instructed to draw a line connecting circled numbers and letters while alternating between numbers and letters in ascending order. The TMB's primary outcome measure is time to completion.

The *Wisconsin Card Sorting Test* (WCST; Loong, 1990) is a well-known executive function test that assesses set shifting, concept formation, and utilization of feedback. A computerized version of the WCST was used in the present study. Outcomes of interest were percent perseverative errors and the number of categories completed.

The *Tower of London* (TOL; Shallice, 1982) assesses planning ability and problem-solving skills. This task requires participants to move beads to match model goal arrangements while following specific rules. A computerized version of the TOL was used. The total number of excess moves beyond the minimum required to complete all models was used as the outcome measure.

Verbal Fluency (VF; Delis et al., 2001) includes two subtests, one of which involves phonemic/letter fluency and another involving category/semantic fluency. The total number of words in each subtest was the outcome measure of interest.

The *Symbol Span Test* (Wechsler, 2009) is a subtest of the Wechsler Memory Scale – IV (WMS-IV; Wechsler, 2009) that assesses visual working memory. Visual figures of various shapes are presented on a page, after which participants are presented with a recognition page that includes both target and distractor shapes. Examinees are to select the items that were previously viewed in the same sequence in which they had been presented. The outcome measure was total points earned.

The *Digit Span* task (DS) is a subtest of the Wechsler Adult Intelligence Scale-IV (WAIS-IV; Wechsler, 2008) that assesses verbal working memory. The DS test includes 3 subtests, all of which involve hearing and recalling digit sequences of increasing length. DS Forward requires repeating digits in the same order they were presented, DS backward involves repeating digits in reverse order from their presentation, and DS sequencing requires that digits be recalled in ascending order. In the present study the DS subtests and the overall DS total score were used as outcome measures of working memory.

The *Conners' Continuous Performance Test* – 3rd Edition (CPT-III; Conners, 2014) is a continuous performance test that evaluates attention, as well as processing speed and response inhibition. The number of commission errors serves as an indicator of response inhibition, with more commission errors reflecting worse response inhibition.

2.2.2.2. Memory. The *Rey-Osterrieth Complex Figure Test* (RCFT; Osterrieth, 1944) assesses visuospatial memory. In the present study, short delay (3 min), and long delay recall (30 min) were used as outcome measures.

The *California Verbal Learning Test* (CVLT; Delis, Kramer, Kaplan, & Ober, 2000) is a word list-based auditory-verbal memory task that assesses immediate and delayed verbal memory. The outcome measures used in the present study were the total number of words recalled correctly in both the short and long delay, and the cumulative number of words correctly recalled on trials 1–5.

2.2.2.3. Attention. The *CPT-III* (Conners, 2014) hit reaction time standard deviation (HRTSD) and omission errors were used as outcome measures to assess attention function. The number of omission errors reflects vigilance-related attention, with fewer omission errors indicating better attention.

2.2.2.4. Processing speed. The *CPT-III* (Conners, 2014) average hit reaction time (HRT) in milliseconds for 'go' stimuli was used to assess processing speed.

The *Trail Making Test,* part A (TMA; Delis et al., 2001) is a graphomotor task that involves drawing lines between numbered circles in ascending order. The TMA was used to assess processing speed as a function of completion time in seconds.

2.2.2.5. Visuospatial function. The *RCFT* (Osterrieth, 1944) copy trial score was used as a measure of visuospatial function.

2.3. Procedure

Graduate student research assistants (RAs) underwent rigorous training conducted by the first and last authors, both experienced neuropsychologists. Training included hands-on instructional training, multiple mock administrations of the neuropsychological battery and the MINI, examination of video recordings, as well as one-on-one in-person evaluations. At the end of each study session, RAs would score all measures and tests. Subsequently, to minimize errors, a dedicated data manager carefully reviewed all scoring for all participants prior to data entry. All participants were requested to avoid taking any stimulant medications, sedatives, or to consume more than two alcoholic drinks 24 h prior to the time of assessment. Participants were seen individually in a quiet lab room, and after signing an informed consent, completed the MINI clinical interview, followed by the neuropsychological battery and the self-report questionnaires, the order of which was counterbalanced. Self-report questionnaires were completed in the lab online via the Qualtrics secured online platform. Each session took ~3.5 h on average, including a 10-min break. All computerized tests and questionnaires were administered on identical laptops designated for the study. This study was approved by the Texas State University Institutional Review Board according to the declaration of Helsinki.

2.4. Analytic plan

Statistical analyses were conducted using IBM SPSS v.27.0 (2020). Nominal demographic variables were analyzed using Pearson's X^2 tests (Fishers Exact Test correction was applied as needed), whereas group differences in continuous variables were assessed using analysis of variance (ANOVA). In cases of violations of homogeneity of variance, the Welch's statistic of robust test for equality of means was employed if needed (Welch, 1938) to maintain power while maintaining alpha at the desired level (Glantz & Slinker, 2001). Pearson zero-order correlations were used to assess associations between symptoms and neuropsychological outcomes. A clinical neuropsychological study was never conducted before in misophonia and thus this report meets formal definitions of a pilot study (Everitt, 2021). Furthermore, since there are no previous published neuropsychological data on misophonia, and thus effect size estimation is not obtainable, power calculation was not performed for the present investigation. However, our sample size (n = 96) is much larger than the average sample size in non-pilot neuropsychological studies (Mean n = 53; Bezeau & Graves, 2001). Furthermore, even though this is a pilot study, with a relatively large sample, we took a conservative approach to avoid familywise inflation of type I error and employed correction for multiple comparisons using the Holm-Bonferroni method (Holm, 1979). Effect size magnitude was interpreted based on Cohen's *d* (2013) where small, medium, and large effect sizes correspond to 0.2, 0.5, and 0.8, respectively. Additionally, all comparative analyses of neuropsychological outcomes were conducted on raw test scores. However, to facilitate interpretation of the test results, mean and standard deviations are also presented in standardized Z scores produced via test norms (see supplementary materials Table S1).

3. Results

3.1. Demographic and clinical variables

No significant group differences were found in age, education, gender, race, or ethnicity (Table 1.). The total study sample was characterized by a plurality of females (69.8%) which was more pronounced in the control group (75%) but with no significant group difference. The samples were ethnically and racially diverse with a numerical minority of participants identifying as White American (42.70%). As expected, the misophonia group scored significantly higher on all the MQ subscores with very large effect sizes including on the intensity of range of trigger sounds (MQ-1, d =1.25*),* types and frequency of misophonic reaction (MQ-2, $d = 1.42$), and overall severity of sound sensitivity (MQ-3, $d = 3.92$). Notably, the MQ mean sub-scores for both the misophonia and controls groups were found to be remarkably similar to those found in a number of previous studies (Frank et al., 2020; Grossini et al., 2022; McKay et al., 2018; Wu et al., 2014; Zhou et al., 2017). The misophonia group also presented with significantly higher levels of general anxiety as measured by the DASS-21 Anxiety (d = 0.5), state-anxiety as measured by the STAI-6 (d = 0.62), and impulsivity (d = 0.71) as measured by the I-7. No significant group differences were found for depression and stress symptoms as measured by the DASS-21 although numerically the misophonia group scored higher than controls on the DASS-21 Depression ($d = 0.22$) and Stress ($d = 0.41$) scales (see Table 1).

3.2. Neuropsychological test performance

Group comparisons on all neuropsychological outcomes are presented in Table 2 by neuropsychological domains and subdomains. See standard Z scores computed using test norms in supplementary materials (Table S1.). For a graphic depiction see Fig. 1.

3.2.1. Executive function

No significant group differences were found on tests assessing set shifting (d range = 0.27–0.36), planning ($d = 0.16$), working memory (d range = 0.02–0.33), or response inhibition ($d = 0.02$). On tests of verbal fluency, although there was no significant difference on the letter fluency score (d = 0.02), a significant difference that survived multiplicity correction was found for category/semantic fluency (d = 0.47). Overall, a significant difference was found only on 1 out 12 executive function outcome measures.

3.2.2. Memory

No significant group differences were found on non-verbal memory performance as measured by the RCFT including the immediate (d = 0.20) and delayed memory ($d = 0.30$) trials, both of which showed small effect sizes (see Table 2). In contrast, a significant group difference was found on the CVLT short delay recall on which the misophonia sample underperformed (d = 0.63). This comparison survived correction for multiple comparisons**.** No significant differences were found for the CVLT sum of trials 1–5 or long delay recall. However, although not significant, small effect sizes favoring performance in the control group were found (d*'s* = 0.37 and 0.44 respectively).

3.2.3. Processing speed

No significant group differences were found on the TMA ($d = 0.31$), or the CPT-III task HRT ($d = 0.23$).

3.2.4. Attention

No significant group differences were found in the number of CPT-III

Table 2
Neuropsychological test performance across misophonia and control groups.

	Misophonia M (SD)	Control M (SD)	F	Sig.	Cohen's d
Set shifting					
Trail Making B	80.00 (23.25)	69.86 (32.91)	2.43	0.12	0.36
WCST Preservative Errors	10.25 (6.05)	8.63 (4.54)	2.14	0.15	0.30
WCST Categories Completed	5.44 (1.52)	5.77 (0.88)	1.34	0.25	0.27
Planning					
TOL Excess Moves	6.91 (7.69)	5.80 (6.60)	0.52	0.47	0.16
Working Memory					
DS Forward	11.28 (2.08)	10.59 (2.07)	2.35	0.13	0.33
DS Backward	9.09 (2.52)	9.25 (1.96)	0.11	0.74	0.07
DS Sequencing	8.91 (2.31)	9.52 (2.40)	1.41	0.24	0.26
DS Total	29.19 (5.23)	29.31 (5.15)	0.01	0.91	0.02
Symbol Span Total	29.03 (6.53)	28.92 (6.02)	0.01	0.94	0.02
Verbal Fluency					
Letter Total	38.63 (7.11)	40.02 (10.44)	0.59	0.45	0.16
Category Total	39.38 (5.10)	42.61 (8.38)	5.48	**0.02***	0.47
Response Inhibition					
CPT Commission Errors	50.13 (7.28)	50.30 (9.51)	0.01	0.93	0.02
Verbal Memory					
CVLT Short Delay Recall	10.59 (3.33)	12.34 (2.13)	7.34	**0.01***	0.63
CVLT Sum of Trials 1–5	52.28 (9.52)	55.56 (8.10)	3.11	0.08	0.37
CVLT Long Delay Recall	11.69 (3.01)	12.84 (2.15)	3.76	0.06	0.44
Non-verbal Memory					
RCFT Immediate	21.91 (5.62)	23.19 (7.05)	0.80	0.37	0.20
RCFT Delayed	20.97 (5.45)	22.83 (6.90)	1.77	0.19	0.30
Processing Speed					
Trail Making A	26.72 (8.51)	24.25 (7.24)	2.21	0.14	0.31
CPT Mean RT[1]	49.62 (7.68)	47.54 (10.41)	1.00	0.32	0.23
Attention					
CPT Omission Errors[1]	48.84 (8.76)	48.73 (8.66)	0.00	0.95	0.01
CPT RT SD[1]	49.09 (8.00)	47.13 (10.32)	0.89	0.35	0.21
Visuospatial Function					
RCFT Copy	34.11 (2.87)	34.95 (1.24)	2.52	0.12	0.38

Note. Analyses were conducted on raw scores; [1] = outcome measure analyses were conducted using t-scores. WCST=Wisconsin Card Sorting Test; TOL = Tower of London; DS=WAIS Digit Span; CVLT= California-Verbal Learning Test II; CPT=Conners' Continuous Performance Test III; RCFT = Rey Complex Figure Test; RT = Reaction time; SD=Standard Deviation. * = significant difference that survived multiplicity correction.

omission errors ($d = 0.01$) or HRTSD ($d = 0.21$).

3.2.5. Visuospatial function

Finally, there was no significant difference on the RCFT copy trial between the misophonia and control groups ($d = 0.38$).

3.3. Comorbidity

A series of Pearson's X^2 tests were conducted to compare the groups on DSM disorders as established via the MINI interview (see Table 3). The groups did not differ significantly on the overall percent of participants meeting criteria for any DSM-5 disorder. However, although not statistically significant, the prevalence of OCD in the misophonia group (9.4%), was threefold higher than in the control group (3.1%). Similarly, within the misophonia group, the prevalence of ADHD (15.6%), any eating disorders (6.30%) and panic disorder (6.3%), was higher than the prevalence in the general population, and nearly twice that of the control group (ADHD, 9.4%; eating disorders, 3.1%, panic disorder 3.1%).

3.4. Functional indices

A series of ANOVAs was conducted to assess group differences in the BFIS functional indices (see Table 4). Self-reported functional impairment scores were significantly higher for the misophonia group on functional domains including home-chores ($d = 0.47$), money management ($d = 0.61$), and driving, ($d = 0.58$) with small to medium effect sizes. In addition, the misophonia group scored significantly higher than controls on the BFIS total mean score (Total Mean Impairment; $d = 0.53$). Group comparisons on the mean percent impaired domains (i.e., the average percent of domains scores that met the test's cutoff scores for impairment in each domain, across participants) indicated a significantly larger percent of impaired domains ($d = 0.64$) in the misophonia group (27%) compared to the control group (11%). No significant differences were found in any other BFIS domains. Nevertheless, numerically across domains, all BFIS functional domain outcomes exemplified worse functioning in the misophonia group. Notably, all mean domain scores within the two groups did not cross the BFIS normative cutoff scores to indicate a meaningful functional impairment (Barkley, 2011).

3.5. Correlations between neuropsychological and misophonia outcomes

Pearson's zero-order correlations were computed between neuropsychological outcomes and the MQ subscale scores within the misophonia group, most of which were not significant (see Table 5). However, four of the correlations were significant. CPT-III number of omission errors (sustained attention) was significantly correlated with the MQ-1 (types and severity of misophonia triggers; $r = 0.41$, $p = 0.019$), with the MQ-2 (types and severity of the misophonic reaction; $r = 0.42$, $p = 0.022$), and with the total MQ score ($r = 0.42$, $p = 0.022$). Digit Span forward (working memory) was significantly negatively correlated only with the MQ-3 score (sound sensitivity; $r = -0.42$, $p = 0.018$). These correlations survived multiplicity corrections. No other significant correlations were identified.

3.6. Correlations between clinical symptoms and misophonia severity

Correlations between general clinical symptoms and misophonia symptoms were examined separately for the misophonia and control groups. Correlations were computed between measures of anxiety,

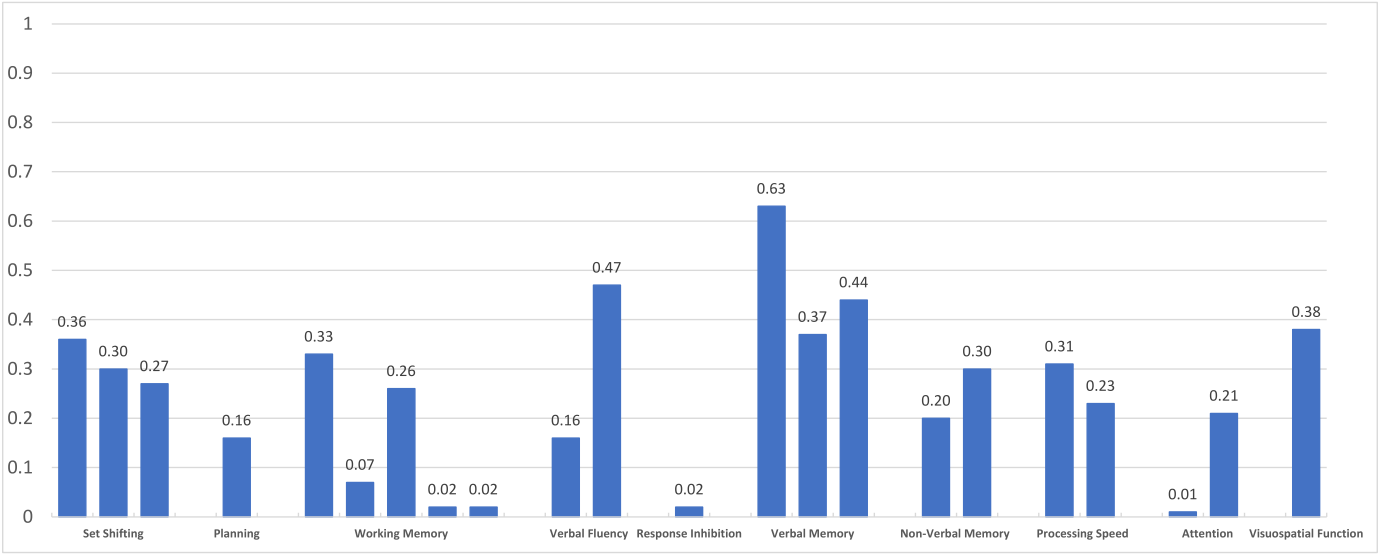

Fig. 1. Neuropsychological domains Cohen's d effect sizes exemplifying underperformance within the misophonia group.

Table 3
Prevalence of current DSM disorders in the misophonia and control groups.

	Misophonia (n = 32)	Control (n = 64)	X^2	Sig.
Major Depressive Disorder	3.10% (1)	7.80% (5)	0.80	0.66
Social Anxiety Disorder	3.10% (1)	3.10% (2)	0.00	1.00
Generalized Anxiety Disorder	3.10% (1)	4.70% (3)	0.13	1.00
Panic Disorder	6.30% (2)	3.10% (2)	0.55	0.60
Agoraphobia	3.20% (1)	3.20% (2)	0.00	1.00
Post-Traumatic Stress Disorder	3.10% (1)	1.60% (1)	0.26	1.00
Obsessive-Compulsive Disorder	9.40% (3)	3.10% (2)	1.69	0.33
Anorexia Nervosa	3.10% (1)	0.00% (0)	2.02	0.33
Bulimia Nervosa	3.10% (1)	3.10% (2)	0.00	1.00
Binge Eating Disorder	3.10% (1)	0.00% (0)	2.02	0.33
ADHD	15.60% (5)	9.40% (6)	0.82	0.50
Substance Abuse Disorder	9.40%. (3)	7.80% (5)	0.07	1.00
Any Anxiety Related Disorder	18.80% (6)	15.60% (10)	0.15	0.74
Any Eating Disorder	6.30% (2)	3.10% (2)	0.52	0.60
Any Current Disorder	31.30% (10)	34.40% (22)	0.72	0.46

Note. ADHD = Attention-Deficit Hyperactivity Disorder.

Table 4
Barkley's Functional Impairment domains in misophonia and control groups.

Variable	Misophonia (n = 32) Mean (SD)	Control (n = 64)	F	Sig.	Cohen's *d*
Home-family	2.52 (2.86)	1.58 (2.11)	2.63	0.11	0.37
Home-chores	3.16 (3.08)	1.94 (1.98)	4.08	**0.049**	**0.47**
Work	2.29 (2.98)	1.64 (2.03)	1.20	0.28	0.25
Social - strangers	3.45 (3.05)	2.67 (2.40)	1.56	0.22	0.28
Social - friends	2.29 (2.44)	1.58 (1.83)	2.08	0.16	0.33
Community Activities	2.13 (2.64)	1.77 (2.05)	0.45	0.50	0.15
Education	3.77 (3.14)	2.73 (2.28)	2.71	0.11	0.38
Marriage/ cohabitation	2.45 (3.15)	1.72 (2.59)	1.26	0.27	0.25
Money-management	4.65 (3.06)	2.95 (2.50)	8.23	**0.01**	**0.61**
Driving	2.06 (2.54)	0.78 (1.79)	6.38	**0.02**	**0.58**
Total Mean Impairment	3.11 (2.23)	2.14 (1.36)	5.03	**0.03**	**0.53**
Percent Domains Impaired	26.58% (29.62)	11.29% (15.91)	7.25	**0.01**	**0.64**

depression, stress, and impulsivity, and the three subscale scores of the MQ (see Table 6). Neither DASS-21 Depression nor DASS-21 Anxiety were significantly correlated with any MQ variables for either group. No significant correlations were observed between the STAI-6 (state anxiety) and any of the MQ subtests for either group.

Within the misophonia group, however, impulsivity (I-7) was found to be significantly and positively correlated with the MQ-2 subscale score (misophonic response; $r = 0.45$, $p = 0.01$), and MQ-3 (single item sound sensitivity/severity score; $r = 0.45$, $p = 0.01$), as well as MQ Total ($r = 0.48$, $p = 0.009$). No significant correlation was found between I-7 Impulsivity and MQ-1 (types and severity of misophonic trigger sounds). Within the control group, significant positive correlations were found between the DASS-21 Stress subscale and the MQ-1 ($r = 0.36$, $p = 0.004$), and MQ Total ($r = 0.33$, $p = 0.01$). No significant associations were found between the DASS-21 Stress and MQ subscales for the misophonia sample.

4. Discussion

The present study is the first examination of neuropsychological functions in misophonia, as well as potential clinical and functional correlates.

4.1. Neuropsychological test performance

The misophonia group performed similarly to the control group on nearly all neuropsychological tests (albeit numerically demonstrated generally lower performance), with only two outcome variables that differed significantly, both of which substantially involve verbal memory retrieval: Semantic (category) fluency, and CVLT short-delay free recall. Specifically, the misophonia group significantly underperformed on the CVLT short delay recall trial, with medium effect size ($d = 0.63$) which substantially involves verbal memory retrieval processes. In addition, albeit not statistically significant, we found further indications of poorer verbal memory functioning in the misophonia group [CVLT number of words on trials 1–5 ($d = 0.37$, $p = 0.08$); CVLT long delay recall ($d = 0.44$, p = 0.06)]. Although verbal fluency tasks are often considered tests of executive functions, research suggests that phonemic (letter) fluency is a true executive function whereas semantic (category) fluency reflects verbal memory retrieval processes more than executive

Table 5
Pearson's zero-order correlations between neuropsychological test performance and MQ subscores within the misophonia group.

	MQ-1	MQ-2	MQ-3	MQ Total
Set shifting				
Trail Making B	0.16	−0.09	−0.04	−0.02
WCST Preservative Errors	0.06	−0.15	−0.26	−0.26
WCST Categories Completed	0.25	0.26	0.24	0.17
Planning				
TOL Excess Moves	−0.09	−0.18	−0.17	−0.13
Working Memory				
DS Forward Total	0.03	0.23	**−0.42***	0.26
DS Backward Total	0.17	0.05	−0.09	0.12
DS Sequencing Total	−0.06	0.18	−0.17	0.09
DS Total	0.06	0.19	−0.27	0.19
Symbol Span Total	−0.03	−0.19	−0.07	−0.12
Verbal Fluency				
Letter Total	−0.12	−0.06	−0.30	−0.10
Category Total	0.25	0.03	0.07	0.17
Response Inhibition				
CPT Commission Errors	−0.03	0.05	−0.01	0.08
Verbal Memory				
CVLT Short Delay Recall	0.07	0.21	0.02	0.16
CVLT Sum of Trials 1–5	0.09	0.15	0.12	0.12
CVLT Long Delay Recall	0.13	0.19	0.10	0.15
Non-verbal Memory				
RCFT Immediate	−0.36	0.01	0.07	−0.21
RCFT Delayed	−0.29	0.10	0.06	−0.09
Processing Speed				
Trail Making A	0.08	0.10	−0.02	−0.02
CPT Mean RT	−0.07	0.02	−0.13	−0.01
Attention				
CPT Omission Errors	**0.41***	**0.42***	0.09	**0.42***
CPT RT SD	0.03	0.09	−0.11	0.15
Visuospatial function				
RCFT Copy	−0.18	0.08	0.12	−0.6

Note. * = significant correlation that survived multiplicity correction. WCST=Wisconsin Card Sorting Test; TOL = Tower of London; DS=WAIS Digit Span; CVLT= California-Verbal Learning Test II; CPT=Conners' Continuous Performance Test III; RCFT = Rey Complex Figure Test; RT = Reaction time; SD=Standard Deviation.

Table 6
Pearson's zero-order correlations between clinical variables and the MQ subscales.

		MQ-1	MQ-2	MQ-3	MQ Total
DASS-21 Depression	Misophonia	0.10	0.13	−0.15	0.11
	Control	0.23	0.18	−0.05	0.22
DASS-21 Anxiety	Misophonia	0.02	−0.07	−0.04	−0.12
	Control	0.04	0.13	−0.17	0.08
DASS-21 Stress	Misophonia	0.17	0.04	−0.06	−0.06
	Control	**0.36***	0.23	−0.15	**0.33***
I-7 Impulsivity	Misophonia	0.18	**0.45***	**0.45***	**0.48***
	Control	−0.05	0.19	0.02	0.09
STAI-State	Misophonia	0.15	0.03	−0.17	0.02
	Control	0.19	0.05	−0.07	0.13

Note. MQ-1 = Misophonia Questionnaire subscale - types of and severity of misophonic trigger sounds; MQ-2 = Misophonia Questionnaire subscale - types and severity of the misophonic reaction to these sounds; MQ-3 = Misophonia Questionnaire subscale - the single items sound sensitivity subscale score. * Significant correlations that survived multiplicity corrections.

processes (Bieling, Israeli, & Antony, 2004). Indeed, imaging studies reveal that semantic verbal fluency is associated with the activation of left temporal regions, which are associated with verbal memory retrieval, whereas prefrontal cortex activation, which has been more closely linked with executive functions, is associated in phonemic fluency tasks (Ghanavati, Salehinejad, Nejati, & Nitsche, 2019). As such, the poorer performance on semantic fluency likely reflects reduced verbal memory retrieval and not reduced executive function performance. Indeed, none of the several measures of executive function indicated significant underperformance by the misophonia group relative to the control group. It is unclear at present why verbal memory retrieval specifically would be affected more than other cognitive domains in misophonia. However, functional, and structural imaging studies of misophonia suggests alterations in brain structures and functions associated with verbal memory retrieval, including the precuneus, and temporal lobe structures, including the hippocampus (Eijsker et al., 2021; Kumar et al., 2021; Neacsiu et al., 2022). Notwithstanding, it is notable that the magnitude of effect sizes (small-to-medium in magnitude) pertaining to verbal memory retrieval underperformance found in the present study did not reach a level of cognitive impairment on these tasks (for a discussion see Abramovitch, Short, & Schweiger, 2021).

4.2. Correlations between misophonia symptoms and neuropsychological outcomes

The majority of correlations examined between misophonia symptoms and neuropsychological performance were not significant. The only significant correlations were CPT Omission Errors (a computerized measure of sustained attention), which correlated with MQ-1 (number of types and severity of trigger sounds), MQ-2 (number of types and severity of misophonic response), and MQ-Total, but not with MQ-3 (severity of sound sensitivity and associated impairment). In addition the DS Forward (working memory), was negatively correlated with MQ-3 only. No significant correlations were found on these indices in the control group. Notably, these results reflect cognitive functioning under 'cold' conditions, and not during symptom provocation. Thus, these correlations between misophonia severity and inattention found only in the misophonia group correspond to recent brain imaging findings indicating that misophonia is associated with functional alteration of neural connectivity at rest (i.e., not only during misophonic provocation). It has been argued that such alterations in functional connectivity may be a consequence of repeated misophonic experience (for a review see Neacsiu et al., 2022), and thus may explain why these associations are found under 'cold' conditions. However, more research is needed to elucidate such alterations and their association with attentional functioning in misophonia, particularly under 'cold' versus 'hot cognition' conditions.

It is important to note, however, that these association were found only between two neuropsychological outcomes and misophonia severity. Given that psychopathology has generally been associated with reduced cognitive performance (Abramovitch et al., 2021), the general absence of correlations between self-reported misophonia severity and cognitive performance may seem surprising. However, research directly assessing associations between disorder-specific self-report severity measures and neuropsychological test performance usually yields modest associations at best (David, Zammit, Lewis, Dalman, & Allebeck, 2008; McGrath et al., 2016; Woon, Farrer, Braman, Mabey, & Hedges, 2017) and neuropsychological tests generally are considered poor predictors of the presence of any psychopathology (e.g., Abramovitch, McCormack, Brunner, Johnson, & Wofford, 2019). The modest nature of the associations may stem from the suboptimal psychometric properties of the measures involved, particularly given the known problem with ecological validity in neuropsychological tests (Zivin & Katon, 2015).

The results of this study further indicate an absence of group differences in the prevalence of comorbid DSM disorders. This is somewhat surprising given previous reports suggesting that misophonia is associated with psychopathology (Cassiello-Robbins et al., 2020; Potgieter et al., 2019), particularly OCD/OCPD and ADHD (Rouw & Erfanian, 2018; Taylor, 2017) although some studies have not found substantially higher prevalence rates in misphonia samples (Jager, de Koning, Bost, Denys, & Vulink, 2020; Schroder et al., 2013). The lack of statistically significantly higher prevalence rates in the misophonia group may be attributable in part to the relatively small sample size ($n = 32$), as the numerical prevalence rates in the present study were indeed higher in

the misophonia sample in a pattern that echoes previous studies. These include a high prevalence of ADHD in the misophonia group (16%), which is more than three times higher than the prevalence of ADHD in US adults (4.6%; Song et al., 2021), and higher than the prevalence of ADHD found in the control group (9%). Similarly, albeit not statistically significant, the prevalence of OCD was also elevated in the misophonia group (9%) compared to the control group (3%). This prevalence rate of OCD within the misophonia group is nearly 8-fold higher than the prevalence in the general population (1.3%; Fawcett, Power, & Fawcett, 2020). The same pattern was found for panic disorder in the misophonia sample (6%), which was twice as high as the control group (3%). Overall, despite a lack of statistically significant differences in prevalence rates between the misophonia and control groups, the misophonia group demonstrated numerically higher prevalence for conditions previously reported as more common in misophonia.

In terms of clinical symptoms, there were no significant group differences in depression and stress symptoms (albeit numerically, the effect size for stress was $d = 0.41$ favoring controls, $p = 0.06$). However, there were significantly elevated symptoms of general anxiety and state anxiety in the misophonia group compared to the control group, consistent with previous studies (Guetta, Cassiello-Robbins, Anand, & Rosenthal, 2022; Jager et al., 2020; Wu et al., 2014). Importantly, the present study revealed higher levels of self-reported behavioral impulsivity in the misophonia group compared to the control group. In addition, impulsivity was found to be significantly and positively correlated with the severity of misophonic behavioral response (MQ-2) and sound sensitivity (MQ-3), as well as with the MQ total score, but not with the number of types or intensity of trigger sounds (MQ-1). This finding supports research that suggests misophonia is related to emotional regulation and impulse control problems (Cassiello-Robbins et al., 2020). This is particularly important as emerging research is now considering how emotional dysregulation may play an important part in misophonia. Indeed, the role of 'emotional impulsivity' (i.e., impulsive responsivity to emotions) has been subject to recent interest in psychopathology research. Specifically, it has been suggested that emotional impulsivity may be important in our understanding of psychopathology and may be transdiagnostic (for a review, see Carver, Johnson, & Timpano, 2017).

4.3. Functional impairments

Greater self-reported impairments were observed in the misophonia group in the domains home-chores (household chores and maintenance), money-management (managing bills and debt), and driving (citations and accidents). In addition, the misophonia sample was found to have a significantly higher total mean impairment score as well a significantly higher percent of 'impaired domains', defined as the number of items that received a score falling at or above the 93rd percentile divided by the total number of items scored. The results of this comparison indicated that the proportion of impaired domains in the misophonia sample was twice as high as controls. Interestingly, impairments related to money-management and driving have been associated with ADHD (Bangma et al., 2019; Vaa, 2014), which was a highly prevalent comorbidity in our misophonia sample. These results correspond to other studies that found that misophonia is associated with functional impairments across multiple domains (Guzick et al., 2023; Jager et al., 2020; Remmert, Jebens, Gruzman, Gregory, & Vitoratou, 2022; Rosenthal et al., 2022). Interestingly, a common domain of functional impairment in misophonia is associated with family life that has been found both in adults (Rosenthal et al., 2022) and youth (Guzick et al., 2023). The results of this study – although pointing to numerically elevated functional impairments in misophonia across domains – indicate that there was no significant difference between the misophonia and control samples on the 'home-family' domains. However, a significant difference was found in the domains of 'home-chores', and 'money management', which was found to have the largest effect size. This discrepancy with the results of previous studies may be related to the fact that the present study examined active college students with misophonia, most of which do not live at home with their nuclear family and are required to function more independently. However, it is important to note that in the current study, review of BFIS test norms indicated that although the misophonia sample reported higher functional impairment scores on these domains, these scores did not reach thresholds for impaired functioning on any of the domains. Notably, our review of the literature clearly indicates that there is a need for further research examining domain-specific functional impairment associated with misophonia.

The present study has several strengths including being the first study to compare misophonia and control samples on a comprehensive neuropsychological battery, administration of a psychometrically valid semi-structured diagnostic interview, assessment of everyday functioning, and employment of correction for multiplicity. However, this study is not without limitations. First, the misophonia group sample size was relatively small, with a control/misophonia participant ratio being 2:1. Second, caseness was determined using the MQ3 impairment scale cutoff which does not directly assess misophonia symptoms but rather impairments resulting from sound sensitivity. However, in lieu of a formal categorical diagnostic algorithm, and given that used for this cutoff results in significant overall group differences on the MQ1 and MQ2, and to facilitate comparisons with previous research, we opted to use the MQ3 cutoff. Another limitation of this study is that we did not assess or rule out hyperacusis which may be important for future studies. In addition, there were two technical issues in this study. First, due to a technical error, only ten out of the fifteen BFIS items were administered. However, as per the BFIS manual (Barkley, 2011), each item is a standalone domain with its own norms, and thus the present study was able to examine 10 functional domains – which, to our knowledge, is the first examination of real-life functional indices in misophonia. Additionally, due to a technical error, raw data from the CPT-III test was available only for a small subsample, however standard t scores produced by the program were available for all participants and were used in the final analyses. Furthermore, this study sample comprised college students which may limit generalizability. Indeed, prior studies have demonstrated that enrolled college students with or without psychopathology may exhibit somewhat better cognitive functioning (e.g., Guerra-Carrillo, Katovich, & Bunge, 2017; Twamley, Hami, & Stein, 2004). This effect may reflect the influence of selection bias (e.g., students with psychopathology who are able to remain in college may have characteristics making them more cognitively "resilient"), cognitively beneficial effects of college (e.g., daily engagement in cognitively challenging tasks; engaging with novel and abstract topics; engaging in planning related to time management and meeting deadlines), or a combination of the two. To the extent that active enrollment in college reduces the association between psychopathology and cognitive dysfunction, the current study may underestimate the degree of misophonia-related cognitive underperformance in non-college student populations. Nevertheless, it is important to note that control sample participants were not excluded if they met criteria for DSM disorders, and in fact, the rates of non-misophonia psychopathology did not differ significantly between the samples. Given that most neuropsychological studies utilize control samples screened for psychopathology and neurological conditions, differences discovered in the present study may lend more credibility compared to a study with a highly screened control sample. However, this study is the first of its kind in misophonia, and much more neuropsychological research is needed in misophonia across different samples, particularly in community and clinical samples.

5. Conclusions

The goal of the present study was to conduct the first neuropsychological study of misophonia in the context of 'cold' cognitive function. We identified poorer verbal memory retrieval in misophonia but there

was no indication of a meaningful impairment. In addition, although there was no difference in sustained attention measures between the groups, there was a negative association between attention functions and misophonia symptoms only in the misophonia group. Furthermore, the results of the present study support the role of behavioral/emotional impulsivity in misophonia, which was related to the misophonic response and sound sensitivity but not with the extent and severity of the emotional reaction to trigger sounds. These findings are in line with recent research. We also found elevated rates of OCD and ADHD in the misophonia sample. However, since this is the first study of its kind, and given the dearth of research on 'cold' cognitive function research in misophonia, the results of this study should be viewed as preliminary and should be replicated in the various relevant samples (e.g., psychiatric samples, audiology samples). Indeed, there is an urgent need for further research into misophonia, particularly neuropsychological investigations that incorporate psychopathological indices.

Ethics statement

This study was approved by the Texas State University Institutional Review Board according to the Declaration of Helsinki.

CRediT authorship contribution statement

Amitai Abramovitch: Conceptualization, Data curation, Investigation, Supervision, Writing – original draft, Writing – review & editing. **Tanya A. Herrera:** Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Joseph L. Etherton:** Investigation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors report no conflict of interest pertaining to the present study.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbtep.2023.101897.

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