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Complete List of Authors:	Adline, Princita; All India Institute of Speech and Hearing, Department of Audiology; All India Institute of Speech and Hearing, Department of Audiology Nisha, Kavassery; All India Institute of Speech and Hearing, Department of Audiology Prabhu, Prashanth; All India Institute of Speech and Hearing, Department of Audiology Uppunda, Ajith; All India Institute of Speech and Hearing, Department of Audiology
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Assessment of Working Memory abilities in Normal Hearing Individuals with and without Misophonia

Princita Dsouza Adline [1], Kavassery Venkateswaran Nisha,[2] Prashanth Prabhu [3], Ajith Kumar Uppunda[4]

Author Affiliations:

[1] Princita Dsouza Adline , MSc (Audiology), ASLP Grade Ⅱ

[2] Kavassery Venkateswaran Nisha, PhD (Audiology), Scientist B

[3] Prashanth Prabhu, PhD (Audiology), Assistant Professor in Audiology

[4]Ajith Kumar Uppunda, PhD (Audiology), Professor of Audiology

[1, 3] Department of Audiology, All India Institute of Speech and Hearing, Manasagangothri, Mysuru - 570 006, Karnataka state, India.
[2,4] Center for hearing sciences, Center of Excellence, All India Institute of Speech and Hearing, Manasagangothri, Mysuru - 570 006, Karnataka state, India.

Address correspondence to:

Princita Dsouza Adline, Department of Audiology, All India Institute of Speech and Hearing, Manasagangothri, Mysuru- 570 006, Karnataka state, India.

E-mail: adline@aiishmysore.in Contact number: +91 7996892871

ORCID ID of authors

[1] Princita Dsouza Adline - 0000-0002-8231-2715

[2] Kavassery Venkateswaran Nisha - 0000-0003-0788-1800

[3] Prashanth Prabhu - 0000-0002-9878-4733

[4]Ajith Kumar Uppunda - 0000-0002-1368-9834

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Abstract

Purpose: The study aimed to evaluate working memory (WM) abilities in normal hearing individuals with and without misophonia using simple and complex working memory tasks and to correlate WM abilities with the severity of misophonia.

Method: The data was collected employing a standard group comparison and a non-probability purposive sampling method. The current study comprised 40 participants aged 18-30 years, who were classified into two groups (with and without misophonia) based on the scores obtained in the Misophonia Assessment Questionnaire (MAQ). Simple tasks including forward and backward digit span and complex tasks including operation and reading span were used to assess WM abilities.

Results: WM abilities, measured using simple WM tasks, were comparable between the two groups. Although the operation span scores revealed no statistically significant difference among the complex tasks, there was a statistically significant difference in the reading span scores.

Conclusions: The performance of individuals with misophonia remained similar to those without misophonia in simple WM tasks. However, their WM performance becomes poorer as tasks become more demanding.

Keywords: misophonia, cognition, working memory

Abbreviations: WM – Working Memory, MAQ- Misophonia Assessment Questionnaire, FUEL- Framework for Understanding Effortful Listening

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Introduction

Misophonia is a complex behavioral and neurophysiologic condition that is characterized by intense emotional responses and aversion to particular auditory stimuli, commonly referred to as "trigger sounds" (Edelstein et al., 2013). It was originally believed that the presence or expectancy of a particular sound made by a person would trigger the patient's aversive response (Arjan Schröder et al., 2013). However, it was later discovered that the triggering sounds could also be everyday sounds – both human-made and environmental - and the reaction to sounds was influenced by the environment and the individual's characteristics (Siepsiak & Dragan, 2019). The heightened emotional response in misophonics after triggers is often linked to the activation of the autonomic and limbic systems (Jastreboff & Jastreboff, 2002).

This neurophysiological link is further supported by the co-occurrence of tinnitus and hyperacusis in individuals with misophonia, both of which exhibit similar patterns of activation in autonomic and limbic mechanisms. Studies underlining the anatomical and physiological correlates of misophonia show evidence of heightened neural activity in the visual cortex, temporal cortex, amygdala, and anterior insula in misophonia patients compared to controls (A. Schröder et al., 2015). Overactivation of the insula and unusual connectivity between cortical regions, including the medial parietal, medial frontal, and medial temporal cortex, with the insula has also been reported (S. Kumar et al., 2017). The brain mechanisms underlying the emotional reactivity and physiological arousal in individuals with misophonia were linked to aberrant myelination in the medial frontal cortex (Suárez et al., 2022). While the insula and amygdala are involved in the processing emotional stimuli, cognitive control, and regulating autonomic functions (Craig, 2009; Shackman et al., 2011), the temporal cortex is involved in auditory signal processing (Griffiths & Warren, 2004; Hickok & Poeppel, 2007). The involvement of the temporal cortex suggests that hyperactivity of the temporal area to particular sounds (triggers) causes aversion or negative emotions in misophonic, which may be linked to the unusual connectivity of the insula with the temporal cortex. Recent research also indicates that misophonic reactions are not solely driven by the auditory characteristics of sounds; other sensory inputs, including those from different modalities, significantly contribute to the aversive response (Samermit, Saal, & Davidenko, 2019; Samermit et al. 2022). It is also reported that responses to misophonic triggers are influenced by whether the listener accurately identifies the source of the sound. Trigger sounds that were

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correctly identified elicited more negative reactions (Savard, Saresm Coffey & Deroche, 2022). Interestingly, the study found no significant difference in sound identification ability between individuals with high and low misophonia symptoms. This suggests that misophonia is not primarily driven by a bottom-up auditory mechanism but is more likely rooted in higher-level neural and cognitive processes (Savard et al. 2022).

While misophonia is primarily associated with emotional responses like anxiety, anger, or disgust, recent studies have suggested a potential impact on attention and cognitive underpinnings in misophonic reactions (Aryal & Prabhu, 2023; Palumbo et al., 2018). It is also observed that individuals with misophonia tend to focus more on details and exhibit cognitive inflexibility which can intensify their aversion to certain sounds, leading to a greater sensitivity associated with the condition (Simner et al., 2021). The cognitive underpinnings of misophonia can be explained using the framework for understanding the effortful listening (FUEL) paradigm (Pichora-Fuller et al., 2016). Individuals with misophonia focus their attention excessively on the sounds that provoke their symptoms. They have trouble diverting away from these unpleasant sounds, which could make it difficult for them to focus on other auditory stimuli (Edelstein et al., 2013; Simner et al., 2021). It is possible to conceptualize that this attentional shift in individuals towards triggers in the environment might interfere with the availability of cognitive resources. Extending Kahneman's theory of the Capacity of Attention Model (Kahneman, 1973), Pichora-Fuller et al., (2016) postulated that when an input is perceived by the system, it triggers a demand for estimation of attention resources within the listeners' capacity. According to the estimated demand, necessary cognitive processes are assigned to the task execution. This process is known as resource allocation policy.

In individuals with misophonia, the mental state of alertness and looking out for triggers in the environment causes anxiety in them, which in turn limits the resources available for the cognitive task (Palumbo et al., 2018). Misophonia severity has been found to correlate positively with anxiety levels (Huviyetli & Çakmak, 2024; Quek et al., 2018), with anxiety mediating the impact of misophonia on quality of life (Huviyetli & Çakmak, 2024). The limited cognitive resources in turn increase listening effort (Rönnberg et al., 2014). Perceptual deficits in cognitive tasks vary based on the complexity of the task being performed. It can be postulated that cognitive demand imparted while performing simple working memory tasks may be compensated by

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increased listening effort (Lemke & Besser, 2016). However, as the tasks become more complex, individuals with misophonia do not have sufficient cognitive resources to overcome the task demand, thus resulting in poor cognitive performance. The role of cognitive processes in misophonia remains largely speculative and not extensively explored.

Working memory (WM) is an aspect of short-term memory, involving the storage and processing of signals in a shorter time window lasting about 20s (Baddeley, 2003). In the present study, WM tasks were chosen to assess misophonia's role in cognitive performance because misophonia has been associated with heightened emotional responses to trigger sounds, which can disrupt cognitive processes like attention and focus. Attention and focus on the incoming signals are needed for target retrieval (e.g. forward and backward digit span) and performing tasks incumbent with memorizing target signal train (reading and operational span tasks). The complexity of the WM task is directly proportional to exerted listening effort (Harvey et al., 2017). The listening effort corresponding to the look out of sound triggers in environment, places misophonics at a disadvantage in processing WM tasks, especially when they are complex tasks. In other words, due to the presence of misophonia, the individual is in constant search of the triggering sounds. This exerts limitations on the cognitive resources needed for listening the incoming sounds, and thus affecting the WM. The FUEL model provides a theoretical framework for understanding how the competition for limited cognitive resources between the misophonic response and the WM task can lead to decrements in cognitive performance (Pichora-Fuller et al., 2016). As WM impairments in misophonics can have a direct bearing on their daily functioning and performance in academic, occupational, and other settings, the authors have chosen to assess the impact of cognitive interference due to misophonia on simple (target retrieval - eg. Forward and backward digit span) and complex (reading and operational span tasks) WM tasks.

Considering the shared cortical resources between the trigger sounds search and memory task (such as WM), it can postulated that misophonics may show poorer performance in the tasks requiring cognition. By investigating these cognitive dimensions based on working memory in misophonic individuals, the study findings might contribute to identifying sensitive tests for cognitive assessment and the development of targeted interventions that can improve their quality of life. The purpose of the current study is to evaluate WM in simple and complex tasks in

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individuals with and without misophonia and correlate the severity of misophonia with WM abilities.

Methods

Study design

Standard group comparison and non-probability purposive sampling were used to gather the data (Schiavetti & Metz, 2006). The participation in the study was entirely voluntary. Informed consent was obtained from all the participants before the evaluations. The institutional ethics and research board approved every procedure used in this investigation (Ref: SH/AUD/2022-23/P01II21S0022). The guidelines for conducting human bio-behavioral research constituted by the institutional ethical committee (Venkatesan, 2009) were followed. These guidelines aligned with the Helsinki Declaration's standards (World Medical Association, 2004).

Participants

The study included 40 participants aged 18-30 years, divided into two groups of 20 each. Group 1 comprised 20 participants with misophonia (mean age: 22.3 ± 3.15 SD years; 20 females), and group 2 had 20 participants without misophonia (mean age: 21.8 ± 1.97 SD years, 20 females). To confirm the presence of misophonia and to indicate the severity, the Misophonia Assessment Questionnaire (MAQ) (Dibb et al., 2021) was administered to all the participants. The data collection was initiated pre-COVID before the psychometrically validated questionnaires were available. Hence, MAQ was used in the present study. All participants had access to the questionnaire via Google Forms delivered by email or social networking sites including Instagram, Facebook Messenger, and WhatsApp. There were twenty-one questions on the questionnaire that evaluated how misophonia affected individual's social and emotional lives. The Misophonia Assessment Questionnaire is rated from 0 to 3 points depending on how frequently the issue applies (0 = not at all, 1 = occasionally, 2= frequently, and 3 =nearly always). Scores of 0-21 indicate mild, 22–42 moderate, and 43-63 severe Using the total score, misophonia severity is determined. Out of the 221 respondents who answered the questionnaire, 20 were included in the

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study based on their MAQ scores. According to a modified Kuppuswamy scale (Kumar et al., 2022), all of the participants were in the upper-lower to upper-medium socioeconomic level. Group 1 consisted of individuals with misophonia symptoms and a MAQ score between 1 and 64 (mean score: 21.9 ±10.42), while group 2 included participants without misophonia symptoms and an MAQ score of 0.

INSERT TABLE 1

The other inclusion criteria included normal peripheral hearing sensitivity, normal middle ear and auditory nerve functioning as inferred from pure tone hearing thresholds, tympanometry, and reflexometry respectively. Hearing thresholds were obtained using a two-channel diagnostic calibrated audiometer Inventis Piano (Padova, Italy) with the TDH-39 headphone (Farmingdale, New York, USA) at octaves from 250 Hz to 4000 Hz (Clark, 1981). All the participants had 'A' or 'As' type tympanogram with acoustic reflexes present (Ipsilateral and Contralateral) at 500 Hz and 1000Hz at normal sensation levels, confirmed using calibrated GSI Tympstar pro (Grason Stadler, Eden Prairie, MN, USA). Participants with co-occurring diseases such as tinnitus, vestibular migraine, hyperacusis, and/or hearing loss, who used hearing aids, who had received musical training, or who complained of otological impairments or neurologic problems were excluded from the study. Prior to each participant being included in the study, an informal interview was used to gather this information.

Assessment of working memory

Working memory was assessed using the Smriti-Shravan software (A. Kumar & Maruthy, 2012). A laptop (Lenovo Ideapad 300-15ISK Core i5 6th Gen) with a Smriti-Shravan module installed and linked to Sennheiser HD206 headphones (Wedenmark, Germany) was used to provide the stimuli. Simple WM tests including forward and backward digit span and complex WM tests including operation span and reading span were administered to each participant.

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Forward and backward digit span: Digit sequences from 0 to 9, with the exception of 7 (which is bi-syllabic), were presented in auditory mode. Inter-stimulus interval of 1000 ms and a response time of 10,000 ms were used. Participants were instructed to enter the numbers on the keyboard in the same sequence as they appeared for the forward digit span test and in the reverse order for the backward digit span test. The adaptive staircase technique (Levitt, 1971) was used to track the forward digit span. Based on the accuracy of the response, the software raised the level of difficulty of the next stimulus sequence. E.g., if the participant accurately entered 4 digits in the forward digit span task, the software raised the sequence in the next presentation to have 5 digits. Before beginning with the actual test, 1 practice trial was given. The responses were statistically analyzed based on the maximum number of digits recalled.

The conventional Digit Span test uses live-voice tests in that it commences with trials that ascend in length until a stopping criterion is met. The maximum score of recall is termed a digit span. However, in the current study, an adaptive procedure is used. This alteration helped the experimenters to immediately provide feedback to the participant, whenever wrong the software reduced the digit by one. Eg., if the participant was to recall 4 numbers in the digit span test, and only could do so for the first 3 numbers, the software recorded the response as incorrect. Instead of again presenting at the same level i.e. 4 digits, the next stimuli set was adjusted to 3 digits. This indirectly provided feedback that the participant failed to correct recall, which in turn urged for allocation of better recall. This procedure for evaluating digit span for assessing working memory in adults is proven to increase accuracy, and internal reliability, and helps in fast automated scoring, making the test highly suitable for clinical use (Dillon et al., 2024).

Operation span and reading span: The operation span task and reading span task which were used in Smrithi Shravan were adapted from the versions used by Kane et al. (2004). Both the tasks consist of 12 items and the number of elements per item varied from 2 to 5. The difficulty of the items was randomized such that the number of elements was unpredictable at the outset of an item.

Monosyllabic words and arithmetic equations were presented in series for operation span whereas; monosyllabic words and sentences were presented for reading span. Participants were instructed to solve the arithmetic problem for the operation span task or judge the semantic/pragmatic correctness of the sentence for the reading span task (secondary task) and

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remember the words. The inter-stimulus interval of 1000 ms and response time of 15,000 ms was used. At the end of each trial, they were asked to choose all the target words in order.

In the operation span task, each element consisted of a mathematical operation and a word (e.g., IS [8*5] -25 = 21 ? and SNOW). The participant's task was to read the math problem aloud, say yes or no to indicate whether the given answer was correct or incorrect, and then say the word. After all the elements in an item were presented the participant was required to write the words in the correct serial order. In the reading span task, each element consisted of a sentence, followed by a letter (e.g., Suresh was stopped by the policeman because he did not use a helmet ? and R). The participant's task was to say the sentence aloud, respond yes or no to indicate whether the sentence made sense or not, and then say the letter. As with operation span, after all the elements in an item were presented, the participant was required to write the letters in the correct serial order.

The inclusion of the word element in the operation span task is likely to assess both working memory and parietal function, as the task requires holding the word in memory while also processing the arithmetic operation. This dual-task requirement, involving both working memory and parietal function for processing the mathematical operation, may have implications for assessing misophonia, as both cognitive control and sensory processing are relevant to this condition (Edelstein et al., 2013; S. Kumar et al., 2017). The word element in the operation span task taps into verbal working memory, which is impaired in individuals with misophonia (Madappally et al., 2024). Additionally, the parietal cortex, which is involved in the processing of mathematical operations, may also be implicated in misophonia as their attention to problem-solving might be compromised. Thus, the operation span task with the word element may provide a useful tool for assessing both cognitive and parietal functioning in misophonia.

The scoring was adapted from the guidelines recommended by Conway et. al (2001). Partial Credit Scores Weighted (PCSW) derived from proportion score was used to analyze the response. The proportion score was obtained by dividing the number of stimuli recalled correctly by the total number of stimuli in the element (e.g., if the participant correctly recalled two of four words, then the score for that item would be 0.25*2 = 0.5). The total proportion score

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was calculated as the average of the item proportion scores multiplied by 100 to yield a scale of 0–100.

Statistical analyses

Data analysis was conducted using the Statistical Package Social Sciences (SPSS), version 26.0. To ascertain if the data was normally distributed, the Shapiro-Wilk test of normality was employed. For each of the measurements (forward digit span, backward digit span, operation span, and reading span) for both groups, descriptive statistics (median with interquartile range- IQR) were performed. Given the limited sample size, a Mann-Whitney U test (Mann & Whitney, 1947) was used to compare the groups. The effect size was determined using the Rosenthal formula, re = /Z// √N, whenever there was a statistically significant difference between the groups (Robert & Rubin, 2003). Also, to assess the relationship between the severity of misophonia and WM abilities Spearman's correlation analysis was carried out.

Results

The Shapiro-Wilk test of Normality was carried out on the scores of WM tests. Results revealed that data follows a normal distribution for forward digit span, backward digit span, and operation span ($p > 0.05$) and a non-normal distribution for reading span ($p < 0.05$).

Descriptive statistics revealed that the scores of WM tests were comparable between individuals with and without misophonia, except for the reading span. Median reading span scores for group Ⅰ is 0.75 (± 0.11 IQR) and for group Ⅱ is 0.83 (± 0.06 IQR). Figure 1 shows the descriptive statistics (with median and IQR) between the two groups. The results of the Whitney test comparing the WM scores across the tasks showed that individuals with misophonia had significantly lower reading scores compared to those without misophonia. However, there was no significant difference ($p > 0.05$) in the performance between the two groups on all the other tasks considered in the study as shown in Table 2.

INSERT FIGURE 1

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INSERT TABLE 2

Spearman's rank correlation was computed to assess the relationship between MAQ scores and WM scores. There was no correlation between MAQ scores and forward digit span, backward digit span, and operation span as shown in Figure 2. However, results revealed a negative correlation between MAQ scores and reading span scores, r (38)=-0.36, p=0.02.

INSERT FIGURE 2

Discussion

The purpose of the current study was to examine WM among individuals with misophonia. All participants underwent WM tests, and results from those with and without misophonia who had normal hearing were compared. For the forward and backward digit span tests, the maximum number of digits recalled was analyzed; for the operation and reading span tests, PCSW was analyzed.

When the digit span scores of all the simple WM tasks (forward, backward) were compared, there was no statistically significant difference obtained among the two groups (Table 2). Based on the findings it is clear that when simple WM tasks like forward digit span and backward digit span tests are used to compare WM abilities in individuals with misophonia, these individuals would not differ from healthy normals. The level of mental load needed to complete each of the digit span tests varies, although they are all classified as simple WM tests. While backward digit span involves the transformation of the sensory input where mental reordering of the digits is done based on the tasks performed while maintaining the input in the short-term memory store, forward digit span does not involve any transformation and is only concerned with short-term memory storage (Hoosain, 1979).

The study conducted to evaluate WM in individuals with tinnitus exhibits these variations in digit spans (Nagaraj et al., 2019). However, the current study failed to show such a trend. Also, when complex WM span tasks like reading span were administered, group differences were seen.

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The absence of statistically significant differences in simple digit span scores between individuals with misophonia and healthy controls in the current study is attributed to the participants exploiting the extended spare time available in simple span tasks for encoding information. The response time (RT) in the forward and backward memory span in Smriti Shravan was 10,000 ms, whereas; it was 15,000 ms for the reading span and operation span task. Individuals need to process and recall only primary stimuli in digit span tests but need to process both primary and secondary stimuli while recalling only primary stimuli in operation span and reading span tasks. This absence of secondary stimuli with sufficient RT available for simple WM tasks could have helped in rehearsal, making the recall simpler in both groups. The presence of distractor stimuli interferes with both encoding and rehearsal of target stimuli (Körner et al., 2019). Hence, it is crucial to prioritize experiments that specifically address this aspect. To shed further light on the WM abilities of individuals with misophonia, an expedited presentation approach, similar to the change-detection paradigm (Rouder et al., 2011) may provide more valuable insights. However, it is essential to note that implementing such investigations would require a departure from the memory test used in the present study. Adopting a different memory test, such as the single-item-memory-probe test along with reaction time measures (in contrast to serial reports like in forward and backward digit span), would be crucial to make a more meaningful comparison with the existing literature (Ricker & Cowan, 2014). In the current study, the participants with any co-morbid disorder like Tinnitus or Hyperacusis were excluded to rule out the influence of those confounding factors on Misophonia. If the comorbid disorders exist, they may cause interaction effects and might skew the data.

In contrast to simple digit-span tasks, complex WM tasks have processing and storage demands. Regarding complex WM tasks, the results of the study revealed that individuals with misophonia performed significantly poorer than the non-misophonic only on the reading span, but not on the operation span. This discrepancy suggests that the challenges faced by individuals with misophonia in complex WM tasks are task-specific and may be related to the cognitive processes involved in reading span. The poorer performance in the reading span task for individuals with misophonia could be attributed to the differences in the task-switching and resource-sharing mechanisms between the two tasks (Saito & Miyake, 2004). The reading span task requires not only the maintenance and manipulation of information but also the integration of semantic content.

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In contrast, the operation span task primarily involves the manipulation and storage of non-semantic information (Conway et al., 1942).

Task switching becomes more demanding in the reading span task, as both the target (information to be remembered) and the distracting stimuli (secondary execution task) carry semantic information. This semantic overlap between target and distractors in the reading span task may exacerbate interference effects and impose an additional cognitive load on individuals with misophonia, contributing to their significantly poorer performance in this specific task. These findings underscore the importance of considering the nature of cognitive processes involved in different complex WM tasks when assessing the impact of misophonia.

When WM abilities were compared with MAQ scores, it was found that WM abilities correlate negatively with the severity of misophonia. This is evident for complex WM tasks as shown in figure 2. This could be due to emotional distress associated with misophonia. As the severity of misophonia increases emotional distress associated would also increase thus resulting in poorer WM abilities (Coifman et al., 2021). Building on this, various attention mediation therapy techniques for managing misophonia, as outlined by Mattson, D'Souza, Wojcik, Guzick, Goodman, and Storch (2023), warrant further exploration through larger, prospective studies to assess their effectiveness comprehensively.

The current study is limited by a small sample size of 20 participants in each group which would not be sufficient to generalize the findings. In addition, MAQ was used to identify the participants which may not be appropriate as it is not validated and meant for young adults (Cervin et al. 2023). Studies in the future should verify the results by using more standardized and validated questionnaires. Further studies on a larger population comparing working memory abilities using different levels of difficulty are required. Also, assessing and comparing WM abilities across the severity of misophonia is recommended.

Conclusion

In conclusion, individuals with misophonia demonstrated comparable performance to healthy controls in simple digit span tasks, indicating similar basic WM memory abilities. However, notable differences emerged in complex WM tasks, with misophonia participants

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exhibiting significantly poorer performance in the reading span task. This task-specific impairment suggests that the challenges associated with misophonia extend beyond basic WM processes, emphasizing the importance of considering the intricacies of cognitive mechanisms in different tasks. Further exploration, incorporating expedited presentation methods and alternative memory tests, is essential to deepen our understanding of misophonia and its impacts on cognition. An additional study involving a larger population is necessary in order to generalize the results.

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Conflicts of Interest

The Authors declare that there is no conflict of interest

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Legends for tables and figures

Table 1

Pure Tone Average and MAQ scores of all the participants

Table 2

Test statistics (/Z/) and significance value (p) for WM tests used in the present study.

Figure 1

Violin plot showing median (centre line) and quartile deviation (error bars) along with individual participants scores (filled circles) for forward digit span, backward digit span, operation span and reading span

Figure 2

Scatter plot showing Spearman's correlation between MAQ scores and WM scores

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Table 1

Pure Tone Average and MAQ scores of all the participants

Sl no.	**Pure Tone Average**		**MAQ score**
	Right ear	**Left ear**	
Individuals with Misophonia			
1	12.5	7.5	56
2	10	11.25	24
3	8.75	10	18
4	11.25	8.75	15
5	12.5	7.5	12
6	13.75	10	28
7	5	6.25	40
8	6.25	12.5	25
9	8.75	10	20
10	13.75	11.25	19
11	10	5	16
12	11.25	7.5	22
13	7.5	11.25	28
14	10	13.75	18
15	15	12.5	15
16	13.75	10	16
17	10	7.5	12
18	11.25	11.25	23
19	7.5	10	15
20	13.75	13.75	16
Individuals without Misophonia			
1	5	12.5	0
2	8.75	7.5	0
3	13.75	11.25	0
4	11.25	15	0

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5	10	8.75	0
6	11.25	12.5	0
7	8.75	13.75	0
8	10	12.5	0
9	12.5	10	0
10	11.25	8.75	0
11	13.75	7.5	0
12	8.75	10	0
13	10	12.5	0
14	7.5	12.5	0
15	11.25	13.75	0
16	5	11.25	0
17	12.5	15	0
18	10	8.75	0
19	13.75	11.25	0
20	8.75	12.5	0

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Table 2

Test statistics (/Z/) and significance value (p) for WM tests used in the present study.

Tests	Test statistics	*p*-value (effect size)
Forward max	/Z/ = 0.73	0.46
Backward max	/Z/ = 0.62	0.53
Operation span	/Z/ = 0.01	0.99
Reading span	/Z/ = 2.50	0.01*(0.40)

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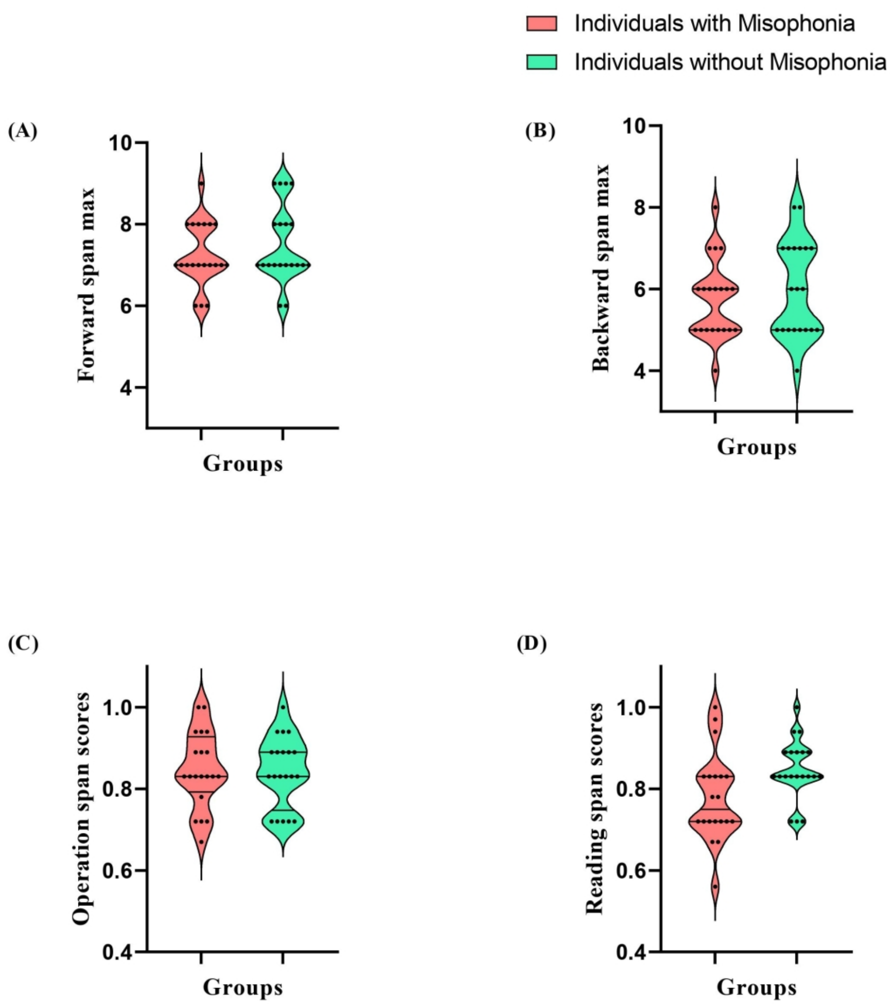

Violin plot showing median (centre line) and quartile deviation (error bars) along with individual participants scores (filled circles) for forward digit span, backward digit span, operation span and reading span

198x212mm (300 x 300 DPI)

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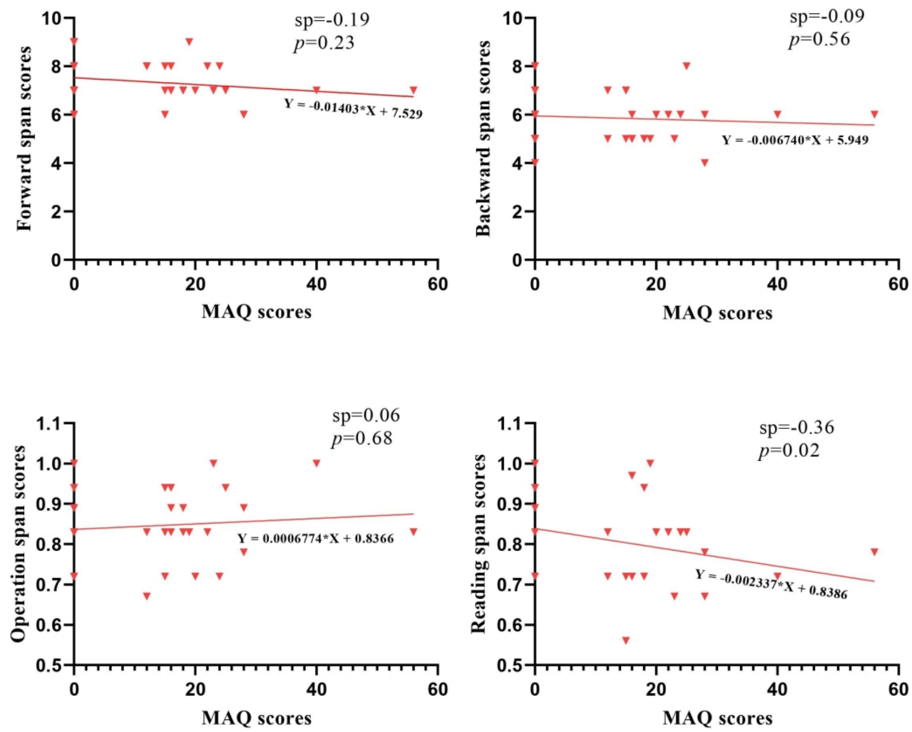

Scatter plot showing Spearman's correlation between MAQ scores and WM scores

209x167mm (300 x 300 DPI)

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