Motion sickness and its impact on auditory spatial perception and working memory

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Running title: Motion Sickness - spatial perception and working memory

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Highlights:

- Motion sickness impairs auditory spatial and working memory performance.
- VASI and digit recall tasks are sensitive markers for motion sickness effects.
- Higher motion sickness levels relate to poorer spatial hearing ability.

Abstract

Background and aim: Motion sickness, characterized by conflicting sensory signals, negatively impacts attention and cognitive functions. This study investigated the effects of motion sickness on auditory spatial perception and working memory in adults with normal hearing.

Methods: A Standard group comparison was conducted on 100 adults with motion sickness, classified into three groups—normal-minimal, mild-moderate, and severe—based on Motion Sickness Susceptibility Questionnaire (MSSQ)-short scores. Standardized assessments were used to evaluate auditory spatial perception, including interaural time difference (ITD), interaural level difference (ILD), and the Virtual Acoustic Space Identification (VASI) test, along with working memory assessed through the forward digit span and 2-back test. ITD and ILD tests involved a discrimination task using psychoacoustic staircase procedure, VASI required identification of virtual locations within head, and memory tasks involved repetition digits and 2nd last digit in sequence, in forward task, and 2-back tasks, respectively.

Results: Participants with motion sickness (mild-moderate and severe groups) performed significantly poorer ($p < 0.05$) than those without on the VASI test, forward digit span, and 2-back. A moderate negative correlation was observed between MSSQ-short and VASI scores. Discriminant function analysis (DFA) revealed that participants with severe motion sickness could be categorized from the other two less severity groups (normal-minimal, mild-moderate), with VASI and forward digit span emerging as the most sensitive indicators of motion sickness induced changes in spatial and working memory.

Conclusion: Findings underscores the importance of monitoring motion sickness, as it can impair spatial processing and working memory tasks in auditory domain.

Keywords: Motion sickness, Spatial perception, Cognition, Working memory, Motion Sickness Susceptibility Questionnaire scores, Vestibular

Introduction

Motion sickness characterized by conflicting sensory inputs regarding body position in space, arises when signals from the vestibular system contradict other sensory information, deviating from past experiences [1]. Abnormal activation of the vestibular system may [2] [3] , lead to the disorienting and often uncomfortable symptoms associated with the motion sickness. This abnormal activation could be due to a variety of factors, such as conflicting sensory signals from the eyes and inner ear, or a disruption in the normal processing of sensory information by the brain [4].

Motion sickness and spatial disorientation affects global population, as much as 60% of astronauts report experiencing motion sickness [5]. Individuals experiencing motion sickness often presents a range of debilitating symptoms including nausea, vomiting, sweating, unsteadiness, feeling cold, clammy, and disoriented [6, 7].

Motion sickness is believed to impact memory, attention, mental imagery, body awareness, social cognition, and spatial working memory [8]. A growing body of evidence points at gender [9], and age bias [10] in spatial perception tasks in individuals with motion sickness susceptibility. Women and older adults generally tend to perform worse on spatial orientation tasks and report higher motion sickness susceptibility compared to men and younger adults [9,10]. Additionally, studies have shown an that spatial attention and expectation across auditory and visual modalities play a crucial role in guiding perceptual decisions [11,12].. Although spatial expectations develop gradually in auditory processing, they generalize well across modalities once formed. However, motion sickness may may disrupt this integration [13], which may further impair spatial perception and working memory.

To understand these connections, our study employs the Motion Sickness Susceptibility Questionnaire (MSSQ)-short to assess the presence and severity of motion sickness [14]. The auditory spatial perception is gauged through interaural time difference (ITD) thresholds, interaural level difference (ILD) thresholds and the Virtual Acoustic Space Identification (VASI) scores. Working memory capabilities (forward memory span and 2n back) are examined using the Smriti Shravan software [15].

Methods

Ethical approval and informed consent. The study was approved by the ethics committee of the institutional review board on bio-behavioural research (Ref: SH/AIISH/AUD_08/2024_25 dated 26.7.2024). Informed consent was obtained from all the participants involved in the study. Participants were provided with detailed information about the study's purpose, procedures, potential risks, and they voluntarily agreed to participate by signing a consent form.

Participants. The study comprised 100 adults with motion sickness (53 males and 47 females) and normal-hearing, aged 19 to 26 years (mean age: 23.22 ± 1.83 years). Participants were recruited using purposive sampling from the cases reported in outpatient department of All India Institute of Speech and Hearing, Mysore. The sample size was calculated using G*Power version 3.1.9.7 [16] for the power 0.8, significance (α) of 0.05, and moderate effect size (f) of 0.4. Using a one-way repeated measures ANOVA for three groups, a sample size of 66 participants is sufficient to detect a moderate effect size of 0.4 with adequate statistical power. However, in this study, we recruited 100 participants to account for variability and to enhance the generalizability of the results.

Eligibility required normal hearing sensitivity, as documented by pure-tone audiometry (air and bone conduction thresholds ≤15 dB HL from 250 Hz to 8 kHz), and normal middle ear function confirmed by immittance audiometry (Type A tympanogram and normal acoustic reflexes). The inclusion of participants with normal hearing was a deliberate methodological choice to avoid the confounding effects of hearing loss on the spatial and cognitive outcomes.

Exclusion criteria included history of chronic ear infections, upper respiratory tract infections, significant noise exposure, pharmacological ototoxicity, neurological disorders, cognitive impairment, or other medical conditions that could affect study outcomes. Individuals undergoing vestibular or balance rehabilitation, taking medications known to influence vestibular function, motion sickness, or cognitive performance (such as antihistamines or psychotropic drugs) were excluded. Participants engaged in Yoga, professional music training, or intense physical exercise were also excluded. Furthermore, participants with poor nutritional status, preferences [17] were not enrolled. All candidates underwent a disordered sleep patterns or varied diurnal

structured interview, medical history review, and audiological evaluation to ensure that they met all inclusion and none of the exclusion criteria . An informal interview addressed lifestyle factors such as dietary habits, physical activity, sleep quality, and socialization. Demographic characteristics were balanced between groups regarding sleep duration (≥ 7–8 hours), work-related stress, alcohol consumption, and education levels (graduate and postgraduate).

Participants were categorized into 3 groups based on their MSSQ-Short [6] scores : no motion sickness/ normal (Group I, n = 33, mean age = 26 ± 1.83 years), mild – moderate (Group II, n = 34, mean age = 26 ± 1.33 years) and severe motion sickness (Group III, n = 33, mean age = 28 ± 1.97 years) MSSQ-short is a validated tool with high internal consistency (Cronbach's alpha = 0.87) and test-retest reliability (r = 0.9) [6]. To classify participants, individual MSSQ-short scores were computed, and categorised using percentile-based cut-off norms established in the literature [18]. Participants scoring at or below the 25th percentile were assigned to the none-minimal motion sickness group; those scoring between the 26th and 75th percentiles were categorised as mild- moderate susceptibility group; and participants scoring above the 75th percentile were placed in the severe susceptibility group.

The demographic and clinical characteristics of participants across the three groups is given in Table 1. One-way ANOVA found no significant differences between groups for age (p = 0.062), sleep duration (p = 0.421), and work-related stress (p = 0.814), while MSSQ-Short scores differed significantly (p < 0.001). Chi-square tests showed no significant differences in sex (p = 0.872), education level (p = 0.996), or alcohol use (p = 0.966) between groups. The matching of the groups on key demographic variables, minimizes the risk of confounding factors on the outcome measures (i.e. on spatial processing, and working memory).

Procedure

All participants underwent initial evaluations, which included pure-tone audiometry and immittance testing. Air conduction (AC) thresholds (250–8000 Hz) and bone conduction (BC) thresholds (250–4000 Hz) were measured using Hughson and Westlake's modified method [19]. AC testing was performed with Telephonics TDH-39 supra-aural headphones, while BC testing used a Radioear B71 bone vibrator, both carried out via an Inventis Piano dual-channel clinical audiometer (Inventis, 35127 Padova, Italy). Screening immittance audiometry was conducted at a 226 Hz probe tone (0.5 kHz and 1 kHz, ipsilateral and contralateral) using the GSI Tympstar V 2.0 middle ear analyzer (Grason Stadler Inc.-GSI-61; Milford, NH, USA). All equipments were calibrated according to ANSI S3.6-2018 standards, prior to data collection to ensure measurement accuracy, and reliability.

All participants who had normal hearing sensitivity and middle ear functioning were included in the study. The battery of tests, encompassing auditory spatial processing (VASI test, ITD, and ILD) and working memory (both simple and complex) tests were administered. The auditory spatial processing tests (VASI, ITD, and ILD) were selected due to their ability to precisely assess spatial hearing and binaural integration, which are fundamental for detecting and localizing sounds in complex environments. The working memory assessments (forward digit span and 2-back tasks) were chosen to evaluate both simple and complex short-term memory processes. All assessments were conducted in a sound-treated room with ambient noise levels below 35 dB SPL All assessments were conducted in a sound-treated room with ambient noise levels below 35 dB SPL to minimize distractions and ensure consistency to minimize distractions and maintain consistency. This controlled environment enhanced the validity and reliability of the results.

Motion Sickness Susceptibility Questionnaire – Short:

MSSQ-short, a 16-item questionnaire was administered on all the participants. MSSQ-Short has strong test-retest reliability of r = 0.9, and strong internal consistency (Cronbach's alpha of 0.87, r = 0.68 between child and adult subscales) [14].. It consists of two subsections: Part A, which assesses childhood experiences, and Part B, which focuses on adulthood. MSSQ-Short elicited motion sickness related responses across various motion types like cars, boats, swings, and amusement rides. Participants were asked to rate how often they felt motion sick in each of these situations. The scoring criteria followed the standard MSSQ-Short format, wherein responses that were assigned "Never felt sick" was scored as 0, "Rarely felt sick" as 1, "Sometimes felt sick" as 2, and "Frequently felt sick" as 3. Items marked as "No experience" were not scored and were excluded from the total item count. Scores for childhood and adulthood experiences were computed separately and normalized, and summed to yield a total score from 0 to 48. Higher scores indicate greater susceptibility to motion sickness.

Auditory spatial processing tests

The Virtual Acoustic Space Identification (VASI) test (Nisha & Kumar, [20]), a closed-field spatial acuity assessment test was administered. This test used 250 ms white band noise convolved with non-individualized head-related transfer functions from Sound Lab 3D (Slab 3D version 6.7.3) [21], to create the illusion of eight spatial locations within the head, including mid-line front (0° azimuth), mid-line back (180° azimuth), towards right at 45°, 90°,135° (R45, R90, R135), and towards left at 45°, 90°,135° (L45, L90, and L135).

Stimulus presentation and response acquisition in VASI were managed through Paradigm experimental builder software (Perception Research Systems, 2007). Each participant completed randomized trials of 80 VASI stimuli (8 locations × 10 times). The participants were select the virtual location by clicking mouse button on the graphical user interface displayed on the computer screen [20]. A familiarization task containing 5 trails of each location, was given before testing, allowing participants to click on the location, and hear the corresponding virtual sound. After testing, responses were stored in an excel sheet, which was later analyzed using custom code running on MATLAB [22] to compute overall correct VASI scores. These results from MATLAB code were manually cross-checked to ensure accuracy and reliability of the scoring process. This scoring procedure has demonstrated strong empirical validity in previous studies [20, 23].

Binaural tests involving ITD and ILD were conducted using MATLAB version R2015a with the psychoacoustics toolbox [23]. Each run consisted of three 250-ms stereo noise bursts, two being standards and one variable, with acoustically induced lateralization towards the right ear. For the ITD and ILD tasks, lateralization was achieved through interaural timing variations (delay in the left channel) and level differences (greater amplitude to the right ear) of the variable stimulus. The three-down one-up staircase procedure, converging at 75% of the psychometric function [24], was employed with the test concluding at 10 reversals. The ITD and ILD thresholds were determined by averaging the last 4 reversals.

Working memory tests

Both simple (forward digit span) and complex (2-back task) memory spans were evaluated using the Smriti Shravan software (Kumar, & Maruthy, [15]). This software is tailored for evaluating both auditory and visual working memory and provides visual instructions before each test.

In the forward digit span test, participants heard a series of digits presented binaurally and were instructed to recall them in the same order. The difficulty level of the task was adjusted based on participants' responses: successful recall led to an increase in sequence length for subsequent trials; conversely, incorrect responses led to a decrease. Performance was scored in two ways: the maximum score, representing the longest sequence recalled, and the midpoint score, indicating the averaged sequence length correctly recalled across trials. For consistency and reliability in analysis, only the midpoint scores were used [25].

In the 2n-back task, participants viewed a sequence of digits (1–9), and asked to recall the last but two digits in the sequence. In this task, they were required to maintain a set number of digits in their working memory and continuously update this information. Scores for the 2n-back task were based on the number of correct judgments made during the task, with the software recording response accuracy.

Statistical analyses.

IBM SPSS Statistics, version 26.0 (IBM Corp, Armonk, NY) was used for data analysis. Descriptive statistics, including the median and interquartile range, were employed to summarize the data. The Shapiro-Wilk test was applied to evaluate the normality of the data. Kruskal-Wallis H test followed by Dunn-Bonferroni test was performed for understanding the main effect of group and post-hoc pairwise comparisons respectively. Spearman test was performed to understand if there was any correlation between the tests scores with the MSSQ-Short scores. Also, Fischer discriminant analysis (FDA) was performed for group categorization based on the discriminant function scores (i.e. function describing weightages of each test in group segregation).

Results

The descriptive statistics with median and interquartile range for the three groups across the tests is shown in Figure 1. Shapiro-Wilk's test revealed non-normality of data.

Kruskal-Wallis H test revealed a statistically significant main effect of group for the VASI test, forward span, and 2-back test scores as shown in Table 2. However, no main effect of group was seen for ITD and ILD thresholds. Post hoc analysis using Dunn-Bonferroni pairwise tests gave specific insights into the group differences for each measure. In the VASI test, the participants with severe category of motion sickness displayed significantly lower VASI scores compared to both the none-minimal category ($p < 0.001$) and the mild-moderate category ($p = 0.006$). However, the VASI scores of the none-minimal and mild-moderate groups did not differ

statistically ($p = 0.39$). Participants in the severe category exhibited significantly lower forward digit span scores and 2n back scores ($p < 0.001$) compared to the none-minimal category ($p = 0.002$) and the mild-moderate category ($p = 0.047$). While such differences were not statistically significant between the latter two groups for forward digit span ($p = 0.98$), and 2n back ($p = 0.60$) tasks.

Spearman's correlation test revealed a significant moderate negative correlation between MSSQ-short scores and VASI scores ($S\rho = -0.52$, $p < 0.001$). However, no significant correlation was found between MSSQ-short scores with either ITD thresholds ($S\rho = 0.20$, $p = 0.06$), ILD thresholds ($S\rho = 0.14$, $p = 0.15$), forward span ($S\rho = -0.01$, $p = 0.85$), and 2-back tests ($S\rho = 0.05$, $p = 0.55$), as shown in Figure 2.

The discriminant functional analyses generated two DFs that categorized motion sickness susceptibility on spatial and cognitive tests. The details of variability accounted by the discriminant function is shown in Table 3. DF_1 was statistically the most robust function ($p < 0.001$) for group segregation, which explained 91.9% of the overall variance. DF_2 accounted for 8.1% of the total variance. Table 4 shows the discriminant function coefficients of each test suggestive of their weightage on DF_1 and DF_2.

The analysis of DF_1 function identified VASI test as the most sensitive metric to capture motion sickness susceptibility, followed by forward span test. The combined group plot obtained using results of discriminant analysis was plotted using DF1 on abscissa and DF2 on the ordinate axis, and a cluster of classification values of spatial and working memory tests for different groups is shown in Figure 3. Table 5 shows the accuracy of classification of each participant's DF scores with their original pre-verified conditions. An overall 60.00 % accuracy in the classification was seen, indicative of the moderate efficacy of DF_1 on group segregation.

Discussion

The study explored the auditory spatial and working memory abilities in adults with motion sickness belonging to different severities. Participants with motion sickness, exhibited deficits in auditory spatial processing and working memory abilities compared to those without motion sickness (Fig 1). Deriving evidence from the earlier studies on role of compromised vestibular system in auditory spatial and working memory skills [8], the present study extends the same findings to motion sickness. Altered vestibular stimulation using cold caloric stimulation led to sound lateralization deficits, in the participants aged 28.23 ± 6.02 years [26]. Research has also demonstrated that motion sickness can negatively impact cognitive performance, particularly short-term memory [27].

The severity of motion sickness influenced participants' performance in the auditory spatial and working memory (Fig 1). In the spatial hearing tasks, the participants with severe motion sickness performed significantly poorer in VASI, compared to less severe groups, while such differences were not seen on the ITD and ILD thresholds (Table 2, Fig 1). This difference could be due to the complexity and the type of cues involved in the VASI task. While ITD and ILD assess basic binaural hearing abilities and involves spatial discrimination task, VASI involves discriminating, categorization and identification of spatial sounds within a simulated three-dimensional auditory space [28]. This places VASI at a higher-level auditory demands task, which requires the integration of spatial cues and cognitive factors like attention. Attention is usually influenced by emotional factors [29]. Participants with severe motion sickness, may experience heightened emotional reactivity during testing, which can interfere with spatial processing abilities. Furthermore, fear and anxiety associated with episodes of motion sickness could contribute to distractibility and a lack of concentration [30]. These emotional factors may lead to the observed differences, particularly in complex auditory tasks, like VASI. However, further research is necessary to firmly establish this relationship, and fully understand the cognitive impact of emotional responses in motion sickness. However, in the less severe forms of the motion sickness, these findings did not hold significance. Secondly, while ITD and ILD involved change of either temporal or intensity between the two ears, VASI comprised of composite cues, including time, level, and spectral variations, making it more sensitive to the changes in spatial processing, subsequent to motion sickness.

On the working memory tasks, participants with severe motion sickness had significantly lower forward digit span and 2n back scores than those with none-minimal and the mild-moderate symptoms, whose performances were similar (Fig 1). This can be explained based on the shared mechanisms in working memory and vestibular functions. The hippocampus, crucial for memory, spatial navigation, and balance in 3D plane [31] receives conflicting sensory inputs during movement, leading to symptoms like nausea and vomiting. The vestibular cortex processes these sensory inputs [32]. Since cognition and vestibular processing involve

overlapping brain regions, motion sickness can impair working memory. Previous studies also revealed similar negative effects of motion sickness on working memory task such as delayed matching to sample [33].

Correlational analysis revealed a moderate negative correlation between MSSQ-short scores and VASI performance, indicating that higher motion sickness severity was linked to poorer auditory spatial ability. No correlation was seen between MSSQ-Short scores and working memory tasks. This suggests that while perceptual ratings reflect vestibular performance, they do not predict cognitive impairments like working memory deficits. Literature supports this finding, that motion sickness, like other vestibular disorders such as benign paroxysmal positional vertigo, vestibular migraine and Meniere's disease show general cognitive deficits [34], particularly in attention, memory, and executive functions. These parallels reinforce the idea that motion sickness can broadly impact cognition, independent of subjective severity ratings (MMSQ-short).

Lastly, the first discriminant function (DF1) of DFA identified the VASI as the strongest predictor of group differences, with the forward span test as the next most significant predictor [Table 4]. Besides emerging as a key metric in discriminant analyses, VASI also revealed significant group differences in the Kruskal-Wallis H test [Table 2], enhancing its diagnostic value for detecting auditory spatial processing deficits motion sickness. VASI's dominance in distinguishing group differences likely stems from its 360° spatial, and its ability to integrate multiple cues. Forward memory span also emerged as a key predictor in DFA due to its sensitivity to cognitive disruptions linked with motion sickness, particularly in auditory-verbal working memory [35]. Thus, the present study underscores the importance of including the VASI and forward span tests for assessing auditory related manifestations of motion sickness.

The strength of the study lies in grouping participants based on the severity of motion sickness and matching for age and gender (Table 1), which enabled a clearer demonstration motion sickness effects on auditory spatial and working memory skills in adults. The findings suggest a relationship between auditory spatial orientation and motion sickness, which may be relevant in contexts involving sensory conflicts, such as virtual environments. However, due to restricted age range (19–28 years), generalizability is restricted. Future research should include a wider age spectrum and larger sample size, examining additional factors such as the frequency and duration of motion sickness episodes, comorbidity conditions that may influence cognitive and spatial processing abilities. Additionally, controlling for known modulators of spatial hearing and working memory—such as diurnal preferences, lifestyle factors, and music training —would improve study rigor. Moreover, incorporating more complex cognitive assessments, including reading span, operation span, cognitive flexibility, and inhibition tasks, will further clarify how motion sickness affects various domains of cognition.

Conclusion.

The study highlights the association between motion sickness, vestibular function, and cognitive performance. Participants in severe motion sickness group performed significantly poorer on forward digit span, 2n back, and VASI tasks compared to less affected groups. The results of the DFA indicated that participants with severe motion sickness could be effectively distinguished from those in the less severe categories (normal-minimal, mild-moderate). Additionally, DFA placed significant emphasis on the VASI and forward digit span, making these the most sensitive measures for detecting motion sickness-related changes in spatial and working memory.

DECLARATIONS

1. Authors' contributions

All the authors have significant contribution and participation in this research.

SU: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing-original draft; RB: Project administration, Formal analysis, Visualization, Writing-review & editing; RJ: Data curation, Formal analysis, Investigation, Writing-review & editing; NKV: Conceptualization, Methodology, Project administration, Software, Supervision, Visualization, Writing-review & editing

2. Competing interests

The authors declare no competing interests that could potentially bias the research or create conflicts of interest.

3. Funding

There was no source of any external funding for the research.

4. Acknowledgements

We would like to express our gratitude to the HoD Audiology for their valuable contributions and support throughout this research. We also acknowledge Director of All India Institute of Speech & Hearing, affiliated to the university of Mysuru for providing access to necessary resources that facilitated this study. The authors also thank the participants for their co-operation for the study.

5. Data and material availability

Upon request, the datasets and materials utilized in this study are accessible.

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Table 1: Demographic and clinical characteristics of participants across groups.

Characteristic	Group I: None-minimal Motion Sickness (n=33)	Group II: Mild–Moderate Motion Sickness (n=34)	Group III: Severe Motion Sickness (n=33)	Test	*p*-value
Age (years) (Mean ± SD)	26.0 ± 1.83	26.1 ± 1.33	28.0 ± 1.97	One-way ANOVA	0.062
Sex (M/F)	17 / 16	16 / 18	15 / 18	Chi-square test	0.872
Sleep Duration (Mean ± SD)	7.8 ± 0.6	7.6 ± 0.7	7.5 ± 0.8	One-way ANOVA	0.421
Work-Related Stress (0–10; Mean ± SD)	3.2 ± 1.1	3.4 ± 1.0	3.3 ± 1.3	One-way ANOVA	0.814
Alcohol Use (occasional/none) (%)	30 / 70	32 / 68	28 / 72	Chi-square test	0.966
MSSQ-Short Score (Mean ± SD)	6.8 ± 2.2	20.5 ± 3.1	40.3 ± 4.0	One-way ANOVA	<0.001

Table 2: Results of Kruskal Wallis H test for the comparison of the main effect of groups

Spatial and working memory tests	H value	*p* value	Effect Size(η_H^2)
VASI	22.38	< 0.001	0.20
ILD	2.40	0.30	0.01
ITD	2.66	0.264	0.01
Forward Span (mid-point)	56.78	0.002	0.55
2-back	26.14	< 0.001	0.24

Table 3: Results of discriminant analysis showing variability and the significance accounted by discriminant functions: DF1 and DF2

Discriminant function (DF)	Eigen value	Variance (%)	Canonical correlation	Wilk's Lamda (λ)	Chi-square ($\chi 2$)	df	*p*
DF 1	0.44	91.90	0.55	0.67	39.16	10	<0.001

DF 2	0.04	8.10	0.19	0.96	3.68	4	0.45

Table 4: Discriminant function coefficients of spatial and cognitive tests, suggestive of the weightage of each test in group segregation of participants on DF1 and DF2

Tests	**Function 1 (DF1)**	**Function 2 (DF2)**
VASI	0.98	0.28
ILD	-0.21	-0.44
ITD	-0.24	0.96
Forward Span	0.42	0.07
2-back	0.16	0.02

Table 5: Accuracy of discriminant function analyses in comparing predicted group memberships to original group memberships. The total number of participants is listed with the corresponding percentage in parentheses.

Original group	**Predicted Group Membership**		
	None-Minimal symptoms	Mild-moderate symptoms	Severe Symptoms
None-Minimal symptoms	70.8% (34)	16.7% (8)	12.5% (6)
Mild-moderate symptoms	30.8% (8)	26.9% (7)	42.3% (11)
Severe Symptoms	14.3% (4)	14.3% (4)	71.4% (20)

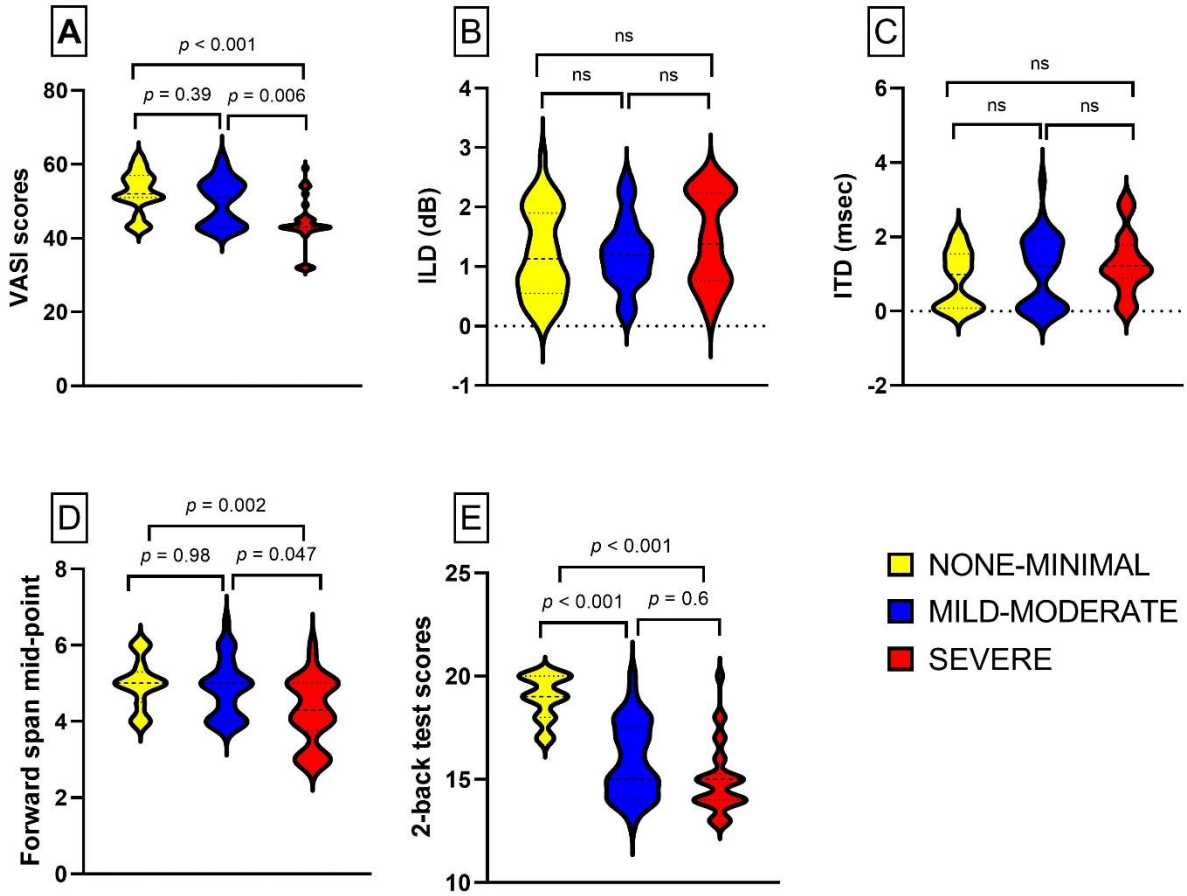

Figure 1: Median scores (middle dotted line) and interquartile range of auditory spatial processing and working memory performance across three groups on : A) Virtual acoustic space identification (VASI) test scores; B) interaural time difference (ITD) thresholds; C) interaural level difference (ILD) thresholds; D) Forward span test scores (mid-point); E) 2-back test scores.

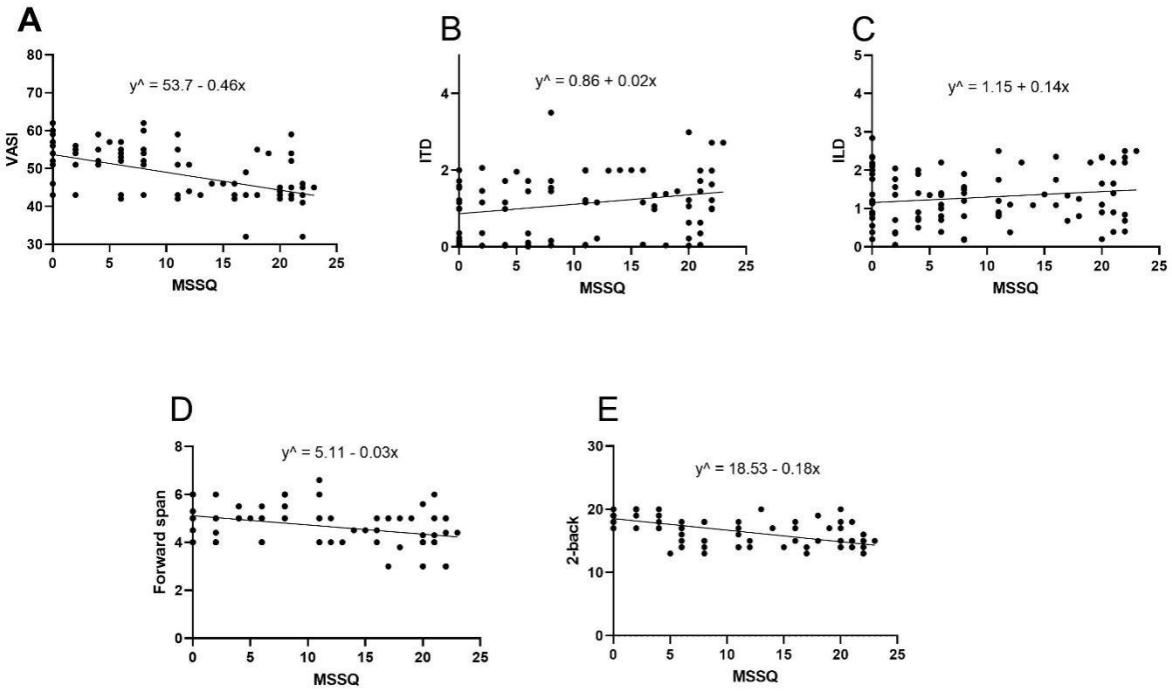

Figure 2: Association between auditory spatial processing/ working memory tests, with MSSQ-Short scores; A) VASI and MSSQ scores; B) ITD and MSSQ scores; C) ILD and MSSQ scores; D) Forward Span scores and MSSQ scores E) 2-back span scores and MSSQ scores

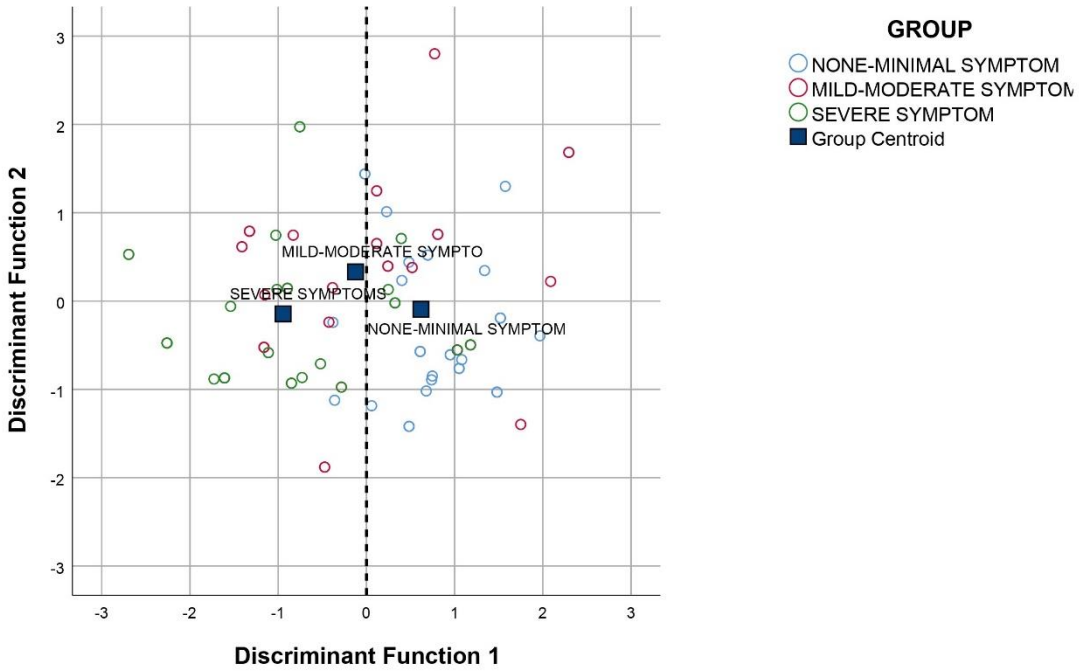

Figure 3: Grouping participants based on canonical discriminant scores derived for auditory spatial processing and working memory tests. Individual scores of each group along with their group centroid is shown.