Research Article

Journal of Vestibular Research
2025, Vol. 0(0) 1–11

DOI: 10.1177/09574271251371540
journals.sagepub.com/home/ver
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Evaluating visual-vestibular interactions in motion sickness susceptibility with static subjective visual vertical, dynamic subjective visual vertical, and rod-and-frame test

Zahra Polat[1,2], Sare Çankaya[1], Burcu Deniz[3], and Mert Kılıç[1]

Abstract

Background: Motion sickness (MS) occurs when the brain receives conflicting signals about body movement from the visual, vestibular, and proprioceptive systems. The otolith organs play a key role in perceiving verticality, and their function may be influenced by MS susceptibility.

Objective: This study aimed to investigate the effect of MS susceptibility on otolith-mediated verticality perception across different head positions.

Methods: Forty-seven participants were classified into two groups based on the Motion Sickness Susceptibility Questionnaire–Short Form (MSSQ-SF): an MS group (n = 24) and a control group (n = 23). All participants completed static Subjective Visual Vertical (SVV), dynamic Subjective Visual Vertical (DVV), and Rod-and-Frame Test (RFT) using a virtual reality system. Measurements were conducted in three head tilt (upright, 30° left, 30° right). The absolute deviation from true vertical was calculated for each test.

Results: While no significant differences were found in SVV performance between groups across head-tilt angles, the MS group exhibited significantly greater deviations in DVV at all positions and in RFT during 30° head tilts. Higher MSSQ scores correlated with greater deviations in DVV and RFT under tilt conditions.

Conclusions: Although static verticality perception remains intact, individuals with MS exhibit greater deviations under dynamic and visually misleading conditions, suggesting subtle vestibular-perceptual deficits.

Keywords

motion sickness susceptibility, subjective visual vertical, rod-and-frame test, head tilt, visual dependence

Received: 11 April 2025; revised: 23 July 2025; accepted: 11 August 2025

Introduction

Motion sickness (MS) has been linked to vestibular function, with the otolith organs playing a key role in processing gravito-inertial cues.[1] Otolith organs detect linear accelerations and gravito-inertial forces, contributing to spatial orientation and verticality perception.[2,3] Bos and Bles[1] suggested that MS results from verticality misperception caused by disruptions in the otolith system or conflicts between otolith input and other sensory systems, including the semicircular canals.

The subjective visual vertical test is one of the tests used to assess verticality perception and serves as a useful clinical tool to assess otolith function[4] and gravity-sensing pathways in both peripheral and central vestibular disorders.[5] Healthy individuals generally complete this task with high accuracy, showing errors between 0 and 2.5°,[6] making it useful for detecting vestibular disorders.[7,8] While static Subjective Visual Vertical (SVV) is conducted against a stable background, dynamic SVV (DVV) assessments introduce motion to examine how the vestibular system processes continuous gravito-inertial cues. DVV is a multisensory integration process that provides insight into how visual

[1]Hamidiye Faculty of Health Sciences, Department of Audiology, University of Health Sciences, İstanbul, Türkiye
[2]Ümraniye Education and Research Hospital, Department of Otolaryngology, University of Health Sciences, İstanbul, Türkiye
[3]Independent Scholar, İstanbul, Türkiye

Corresponding author:
Zahra Polat, Sağlık Bilimleri Üniversitesi, Hamidiye Sağlık Bilimleri Fakültesi, Selimiye, Tıbbiye Cd No: 38, 34668 Üsküdar, İstanbul.
Email: zahra.polat@sbu.edu.tr

adaptation compensates for vestibular impairments.[9] In DVV, when the head remains upright, a sensory conflict emerges as visual inputs suggest movement while the semicircular canals detect no motion.[10] Studies using virtual reality (VR) systems indicate that the mean deviation in SVV is lower compared to that observed in DVV.[11,12]

The Rod and Frame Test (RFT) is another variation of the SVV test used to assess verticality perception in the presence of a misleading static visual reference 13. Unlike the SVV test, RFT specifically measures errors induced by a tilted frame and evaluates the participant's ability to accurately align a rod within this visual context.[14] When the frame is tilted, it influences the participant's perception, causing alignment errors in the rod, which are measured as deviations from true vertical.[15] The RFT is used to assess the field dependence-independence continuum, which reflects the varying dominance of visual cues in multisensory integration.[16] This visuospatial processing style has long been proposed as a defining characteristic of susceptibility to MS.[17]

To better understand vestibular function and perceptual orientation, previous studies have examined verticality perception and spatial reference frames in different patient groups. Miller and Crane[9] investigated SVV and DVV in individuals with migraine and vestibular migraine (VM), reporting greater deviations in visual vertical perception compared to controls, suggesting altered vestibular processing in these populations. Similarly, Chang et al.[18] examined the relationship between visual vertigo and MS in patients with persistent postural-perceptual dizziness (PPPD) and VM. Although no significant differences were found in DVV results among the groups, the VM group exhibited the highest average MS scores, while the PPPD group reported the most severe visual vertigo symptoms.

In addition, RFT has been used to assess the extent to which individuals rely on visual inputs for spatial orientation, including in patients with chronic vestibular symptoms and those experiencing visual vertigo. However, no significant group differences were observed, with only 15% of participants scoring outside the normal range.[19] Likewise, patients with bilateral vestibulopathy demonstrated increased susceptibility to tilted visual frames and greater within-group variability compared to controls,[20] illustrating the role of vestibular impairment in spatial orientation errors.

While studies investigating vestibular contributions to MS sensitivity are limited, one study by Sugawara, Wada[21] examined this relationship using ocular counter rolling (OCR) and head-tilted SVV. They found a significant association between MS susceptibility and OCR but not with head-tilted SVV asymmetry, suggesting that certain vestibular reflexes may be more relevant to MS sensitivity than others. However, given the complex nature of vestibular function and perceptual orientation, further research incorporating additional measures is necessary to better understand the mechanisms underlying MS susceptibility. Building on these findings, this study aimed to examine the effects of MS susceptibility on verticality perception under different head positions and misleading visual cues, with a focus on vestibular and visual interactions. We hypothesized that (1) individuals with MS susceptibility would exhibit greater deviations than controls without MS susceptibility, (2) the presence of motion in the visual environment or misleading visual cues would result in larger deviations in DVV and RFT tasks compared to the SVV condition, (3) MS severity would be associated with increased deviations in the perception of verticality.

Methods

Participants

In this study, undergraduate students aged 18–35 from the University of Health Sciences, Department of Audiology were invited to participate. A total of 274 students received a Google Forms link containing the Motion Sickness Susceptibility Questionnaire–Short Form (MSSQ-SF) and a demographic information form. 231 students completed both forms. Based on their MSSQ-SF scores, participants were classified into two groups: the MS group, and the control group. Participants were then assessed using the demographic information form to determine whether they met the following inclusion criteria:

- Normal or corrected-to-normal vision (e.g., glasses or contact lenses) and no visual impairments affecting balance (e.g., retinal diseases and strabismus)
- No diagnosed vestibular dysfunction (e.g., no history of vestibular disorder diagnosis or documented vestibular pathology)
- Normal hearing, based on self-reported information
- No history of chronic or recurrent middle ear disease (e.g., otitis media, tympanic membrane perforation)
- No current or recent (within the last 6 months) use of medications known to affect vestibular function or MS (e.g., antihistamines, anti-nausea drugs, and vestibular suppressants)

Participants who met the inclusion criteria and agreed to undergo clinical testing were assigned to the MS group (n = 24; 3 males and 21 females) or the control group (n = 23; 4 males and 19 females) following the assessment. Subsequently, all participants underwent the SVV, DVV, and RFT tests.

Motion Sickness Susceptibility Questionnaire short form (MSSQ-SF)

MSSQ-SF assesses MS frequency in two separate sections: before the age of 12 and within the last 10 years[22] It includes

18 questions covering various modes of transportation and amusement rides, such as cars, buses, coaches, trains, aircraft, ships (e.g., Channel ferries), swings in playgrounds, roundabouts in playgrounds, and Big Dippers or funfair rides. Participants indicate their frequency of MS using the categories: "not applicable (t)," "never felt sick (0 points)," "rarely felt sick (1 point)," "sometimes felt sick (2 points)," and "frequently felt sick (3 points)." To calculate raw scores, sickness scores for each mode of transport are summed, with "t" values counted as zero.

The childhood MS score (MSA) is calculated using the formula:[22]

- *MSA = (childhood total sickness score) × (9)/(9−number of types not experienced as a child)*

Similarly, the adult MS score (MSB) is calculated as follows:

- *MSB = (adulthood total sickness score) × (9)/(9− number of types not experienced as an adult)*

The total MSSQ raw score is obtained by summing MSA and MSB, with a possible range between 0 and 54.[23] In this study, individuals with a raw MSSQ score above %80 (MSA + MSB ≥21.6 points) were included in the MS group, while those with a score below 20% (MSA + MSB ≤3.0 points) of the maximum possible score were assigned to the control group.

Static subjective visual vertical (SVV), dynamic subjective visual vertical (DVV) and rod and frame test (RFT)

To assess verticality perception and visual dependence, three different tests (SVV, DVV, and RFT) were conducted using a VR environment (Virtualis BalanceVR V1.0, Interacoustics A/S, Denmark) (see Figure 1). The VR system operated using the HTC Vive Pro 2 headset (HTC, Taoyuan District, Taiwan), which features a 5K resolution display with an estimated pixel density of approximately 23 pixels per degree of visual angle. According to the manufacturer, this level of resolution allows users to detect angular line changes as small as 0.2°, particularly when the visual contrast is high. Head-tilt tracking is managed by the headset's integrated inertial measurement unit, which samples at 1000 Hz and provides a rotational accuracy of less than 0.01°. These hardware specifications are intended to ensure sharp visual presentation and precise head tracking during spatial orientation tasks.

Figure 1. The virtual reality headset and controller used in the study (left). A participant wearing the virtual reality headset and holding the controller during testing in the virtual environment (right).

Participants were seated on an examination table without foot support to minimize proprioceptive input. A wireless controller of the VR system was used to adjust a virtual rod to the perceived vertical position. The tests were conducted in a quiet environment to minimize external distractions.

In all three tests, a total of ten rod angles (−50°, −40°, −30°, −20°, −10°, 10°, 20°, 30°, 40°, 50°) were tested for each participant. Negative angles corresponded to counterclockwise head tilts, while positive angles corresponded to clockwise head tilts. The rod angles were determined by the device in a pseudo-randomized sequence (10°, −30°, 20°, 30°, −50°, −10°, 40°, −20°, 50°, −40°), and the same presentation order was used for all participants to ensure consistency across measurements.

Measurements were taken under three different head positions: −30° (leftward tilt), 0° (upright position), and +30° (rightward tilt) (see Figure 2). The effect of head tilt was assessed across all tests to examine its influence on verticality perception. To prevent head movements from influencing the results, the sway-referenced mode was disabled, ensuring that the virtual rod remained independent of head tilt. The tolerance threshold for head tilt was set at 4.0°.

Participants performed the SVV test by adjusting the virtual rod to what they perceived as vertical against a plain background, without any additional visual cues. In the DVV test, they made similar adjustments while exposed to an optokinetic stimulus that rotated in the direction of the bar inclination. To simulate optokinetic disturbance, the background consisted of white circles rotating at a speed of 15°/s in both clockwise and counterclockwise directions, with the optokinetic stimulus positioned 1 m from the rod to ensure a consistent visual stimulus. For the RFT, participants adjusted the rod to the perceived vertical while exposed to a tilted frame within the "box" environment, where the frame was set at +18° and −18° to assess the influence of visual tilt on verticality perception. The screen images of each test performed in the 0-degree head position are presented in Figure 3.

To minimize potential discomfort or cybersickness, a 15-min resting period was provided after every 15 min of testing. The total duration of all tests was approximately 30 min per participant, excluding the rest periods. Following the completion of all test sessions, the results were automatically recorded and exported into an Excel file provided by VR device. For each rod angle, the absolute mean deviation value was calculated to determine the magnitude of deviation from true vertical.

Statistical analysis

All statistical analyses were conducted using JASP (Version 0.19). Data distribution was assessed using the Shapiro–Wilk test for normality. As the normality assumption was violated in several variables ($p < 0.05$), non-parametric tests were applied for group comparisons and correlation analyses. To assess the equality of variances between groups, Levene's test was used. The Mann–Whitney U test was used

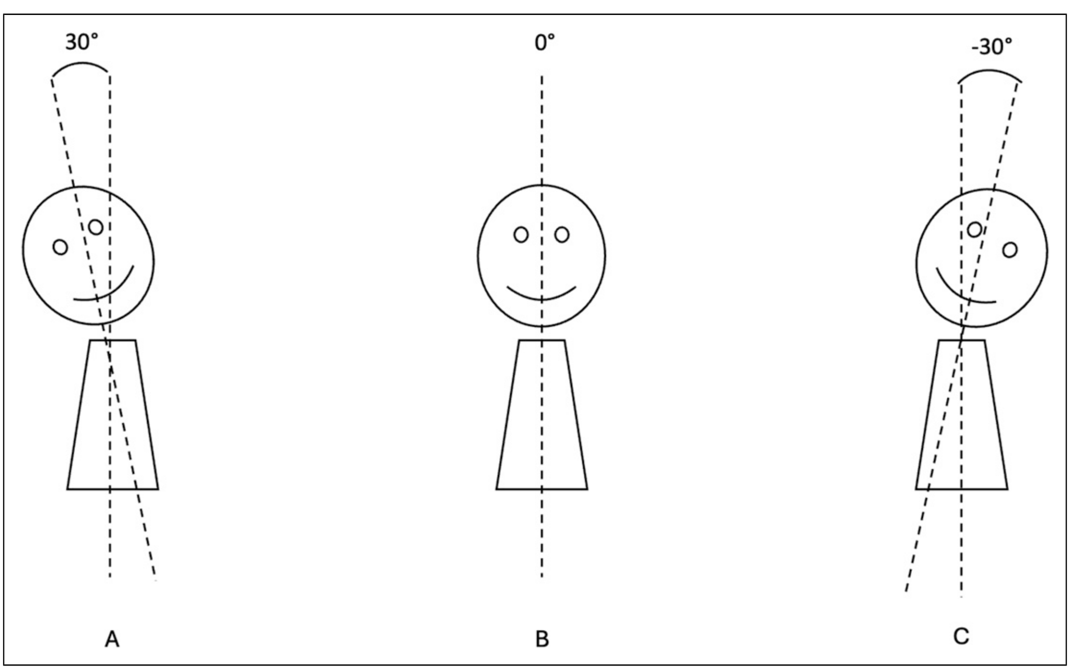

Figure 2. Illustration of head-tilt conditions used in the study. (A) +30° head tilt, (B) 0° upright position, and (C) −30° head tilt. The dashed lines represent the body's vertical axis and the head's orientation relative to gravity. These conditions were used to assess the effects of head tilt on static (SVV) and dynamic (DVV) subjective visual vertical, and rod-and-frame test (RFT) performance.

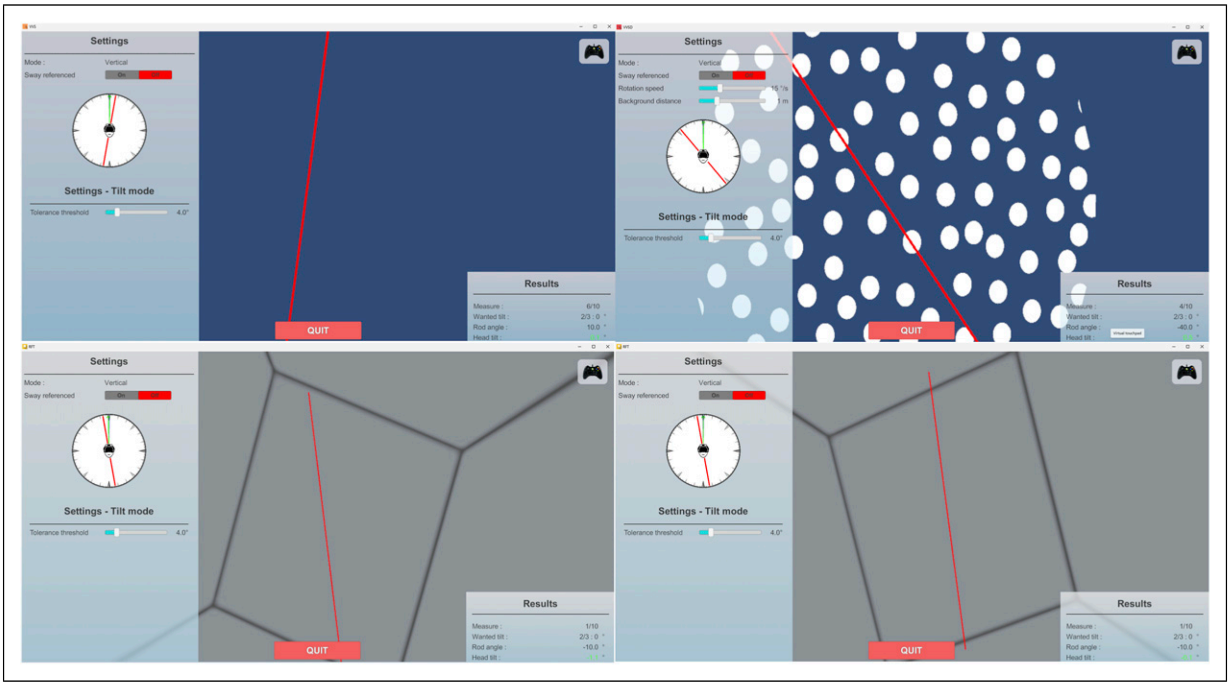

Figure 3. Test screens at a 0° upright position for the static (SVV) and dynamic (DVV) subjective visual vertical, and rod-and-frame Test (RFT) conditions. The top-left image represents the SVV condition, while the top-right image illustrates the DVV condition. The bottom-left and bottom-right images correspond to the RFT condition, with a −18° frame tilt and a +18° frame tilt, respectively.

to compare the control and MS groups. Differences in performance across test conditions at each head-tilt angle were examined using the Friedman test, and when significant effects were found, post hoc Conover-Iman post hoc test were performed for pairwise comparisons. To control for multiple comparisons, p-values were adjusted using the Holm-Bonferroni correction. Correlations between MSSQ scores and deviations in SVV, DVV, and RFT were analyzed using Spearman's rank correlation. The significance level was set at $p < 0.05$.

Results

Levene's test revealed significant differences in variance between groups in specific test conditions. In particular, the MS group exhibited greater variability in the RFT tasks at 0° head tilt ($p = 0.041$ for the −18° frame; $p = 0.034$ for the +18° frame), whereas the control group showed greater variability in the SVV task at 0° head tilt (p = 0.036).

The mean age of the MS group was 22.20 ± 2.70 years, while the mean age of the control group was 23.09 ± 2.91 years. The mean MSSQ score (A + B) of the MS group was 31.32 ± 9.51, while the mean MSSQ score of the control group was 1.09 ± 1.11.

Group comparisons were conducted using the Mann-Whitney U test, and effect sizes (r_{rb}) were calculated to assess the magnitude of differences (Table 1). For SVV, no significant differences were observed between the MS and control groups at any head-tilt angle (−30°, 0°, +30°) ($p > 0.05$), suggesting that static vertical perception remains relatively unaffected by MS.

In contrast, DVV results indicated significant differences between groups with the MS group exhibiting greater deviations in vertical perception compared to controls at −30° head tilt ($p = 0.016$), 0° head position ($p = 0.043$), and +30° head tilt ($p = 0.002$). This indicates a reduced ability to accurately estimate dynamic vertical orientation in individuals with MS.

Significant group differences in RFT performance were observed only under head-tilted conditions. Under −18° frame tilt, the MS group exhibited greater deviations than controls at −30° head tilt ($p = 0.009$) and +30° head tilt ($p = 0.011$). Under +18° frame tilt, the MS group had significantly larger deviations than controls at −30° head tilt ($p = 0.003$) and +30° head tilt ($p < 0.001$), while the difference at 0° head position approached significance ($p = 0.056$) (see Figure 4).

Comparison of different tests at the same head-tilt angles

In both groups, the Friedman test revealed significant differences among test conditions at all head angles (Control: −30°: $p < 0.001$; 0°: $p < 0.001$; +30°: $p = 0.002$; MS: −30°: $p < 0.001$; 0°: $p < 0.001$; +30°: $p < 0.001$) (see Figure 5).

Post hoc tests showed that SVV, which had the smallest deviations, was significantly different from all other tests at

Table 1. Comparison of static SVV) and dynamic (DVV) subjective visual vertical, and rod-and-frame test (RFT) results between the control and motion sickness (MS) groups at different head-tilt angles.

Test	Head angle	Group	Median (IQR)	SD	Min-Max	*Mann-Whitney U*	*Effect Size (r_{rb})*	*p (between groups)*
SVV	−30°	Control	2.96 (3.45)	2.91	1.02-10.66	*221*	*−0.163*	*0.353*
		MS	3.42 (2.44)	4.57	1.34-23.05			
	0°	Control	1.62 (2.20)	1.85	0.75-8.67	*314*	*0.142*	*0.415*
		MS	1.723 (1.23)	1.06	0.51-4.13			
	+30°	Control	3.52 (4.40)	3.9	0.88-13.65	*216*	*−0.143*	*0.423*
		MS	3.84 (5.22)	3.13	1.83-12.74			
DVV	−30°	Control	6.85 (6.01)	3.89	2.63-16.96	*136*	*−0.427*	*0.016**
		MS	10.10 (5.24)	7.15	2.09-36.38			
	0°	Control	4.48 (3.25)	2.26	0.97-9.36	*180*	*−0.345*	*0.043**
		MS	5.85 (4.51)	8.09	1.73-43.89			
	+30°	Control	7.33 (4.87)	4.15	4.32-18.72	*119*	*−0.524*	*0.002**
		MS	12.62 (7.72)	8.68	4.88-47.93			
−18° RFT	−30°	Control	9.99 (5.91)	4.22	1.38-16.57	*221.00*	*−0.444*	*0.009**
		MS	13.67 (6.30)	8.91	5.34-52.00			
	0°	Control	7.50 (4.12)	3.73	0.90-16.54	*314.00*	*−0.261*	*0.133*
		MS	10.01 (10.71)	12.81	1.42-65.50			
	+30°	Control	12.35 (8.11)	4.77	3.59-19.02	*216.00*	*−0.436*	*0.011*
		MS	16.14 (4.95)	12.29	4.83-70.69			
+18° RFT	−30°	Control	11.65 (6.55)	3.99	3.68-17.84	*136.00*	*−0.495*	*0.003**
		MS	16.77 (5.35)	7.24	3.02-38.08			
	0°	Control	8.63 (4.50)	3.45	3.57-16.08	*180.00*	*−0.327*	*0.056*
		MS	11.52 (8.48)	8.58	1.82-46.02			
	+30°	Control	10.87 (5.12)	4.85	3.48-20.61	*119.00*	*−0.549*	*<0.001*
		MS	17.23 (3.86)	4.78	9.42-33.12			

Statistical comparisons were conducted using the Mann-Whitney U test, with effect sizes (r_n). *: $p < 0.05$.

each head-tilt angle in both groups ($p \leq 0.004$). Additionally, DVV, which had smaller deviations than RFT, was also significantly different from RFT at certain head-tilt angles.

In the control group, DVV was significantly different from −18° RFT at 0° head position ($p < 0.001$) and at +30° head tilt (p = 0.005), while no significant differences were observed at −30° head tilt or between RFT conditions.

In the MS group, DVV was significantly different from −18° RFT at 0° head position ($p = 0.006$) and +30° head tilt ($p = 0.005$), and from +18° RFT at +30° head tilt ($p = 0.002$). No significant differences were observed between −18° RFT and +18° RFT in either group.

These findings indicate that SVV (with the smallest deviations) was consistently distinct from other conditions across all head-tilt angles, while DVV (which had smaller deviations than RFT) exhibited selective differences, particularly in the MS group.

Correlations

Spearman's rank correlation was computed to assess the relationship between MSSQ scores and various vertical orientation tasks, including SVV, DVV, and RFT at different head-tilt angles (see Figure 6).

No significant correlation was found between MSSQ scores and SVV at any head-tilt angle (R's = 0.083, $p = 0.582$ for −30°; R's = −0.078, $p = 0.601$ for 0°; R's = 0.208, $p = 0.170$ for +30°), suggesting that MS susceptibility is not associated with deviations in static visual vertical perception.

In contrast, a significant positive correlation was observed between MSSQ scores and DVV deviations at −30° head tilt (R's = 0.347, $p = 0.021$) and +30° head tilt (R's = 0.394, $p = 0.007$), indicating that individuals with higher MS susceptibility exhibited greater deviations in DVV under head-tilt conditions. The correlation at 0° head position (R's = 0.281, $p = 0.056$) did not reach statistical significance.

Regarding the RFT, significant correlations were found between MSSQ scores and deviations at −18° frame tilt in −30° head tilt (R's = 0.366, $p = 0.012$), and at +18° frame tilt in both −30° head tilt (R's = 0.367, $p = 0.011$) and +30° head tilt (R's = 0.448, $p = 0.002$). These results suggest that MS susceptibility is associated with greater susceptibility to visual frame-induced distortions, particularly under head-tilted conditions.

Discussion

This study investigated the effects of head tilt and visual context on verticality perception in individuals with and without MS. While SVV results were unaffected by MS, the MS group showed significantly greater deviations in DVV (with both upright and tilted head positions) and in RFT

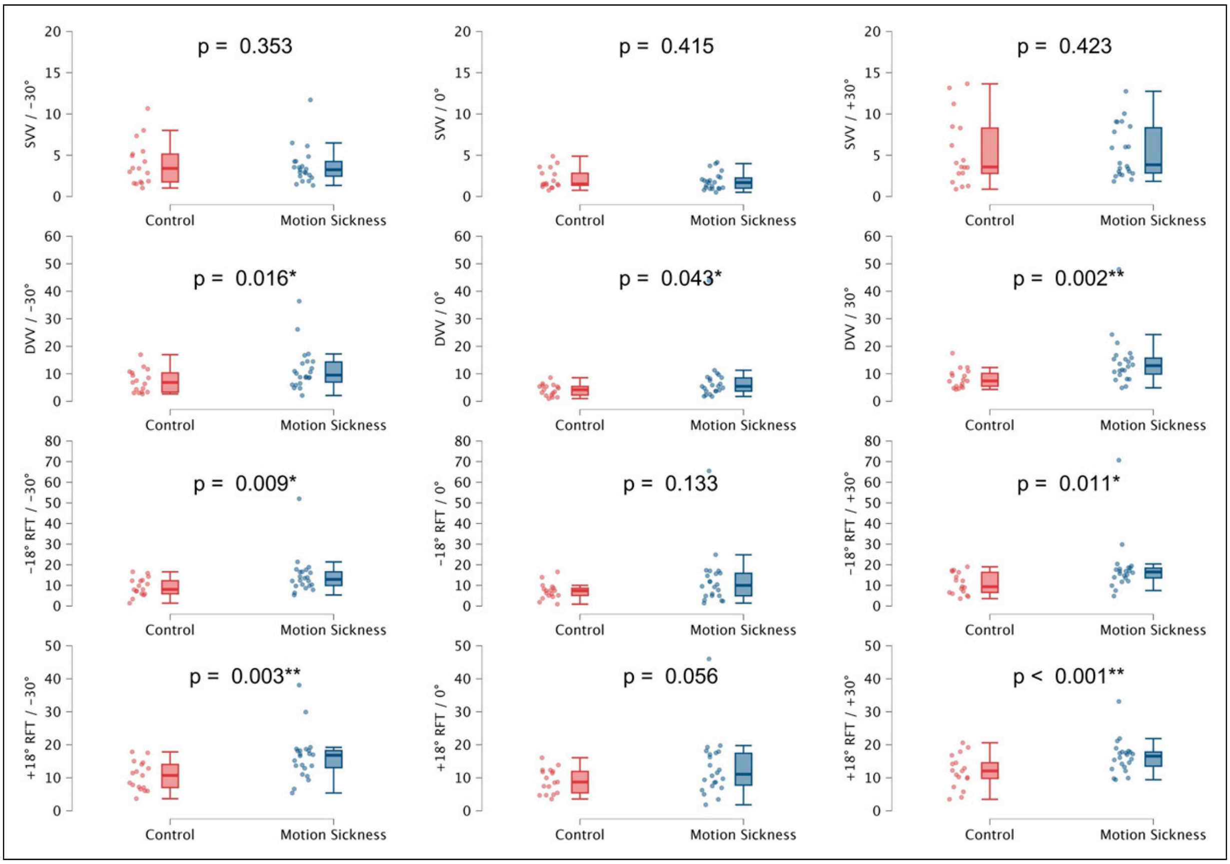

Figure 4. Comparison of test results between the control and motion sickness groups at different head-tilt angles (−30°, 0°, and +30°). The figure presents static (SVV) and dynamic (DVV) subjective visual vertical, and Rod-and-Frame Test (RFT) results at −18° and +18° frame tilt conditions. Each subplot shows the distribution of values for the control (red) and motion sickness (MS, blue) groups. Statistical comparisons between the groups were conducted using the Mann-Whitney U test, with corresponding p-values indicating statistical differences $^{*}p < 0.05$; $^{**}p < 0.01$.

(under head tilt) compared to controls. Additionally, higher MSSQ scores were correlated with greater deviations in DVV and RFT during head tilt, suggesting a link between vestibular deficits and increased sensitivity to visual distortions. In both groups, SVV exhibited the smallest deviations, followed by DVV, with the largest deviations in RFT. This pattern was more pronounced in the MS group.

In an upright sitting position, roll and pitch movements of the head tend to provoke MS, whereas yaw movements typically elicit motion illusions without causing MS.[24] In our study, rod angle deviations were found to be greater under head-tilt conditions than in the upright position across both groups. This finding is consistent with previous studies that reported more pronounced rod deviations during head tilt compared to the upright head position, both in healthy individuals[25] and in patients with chronic dizziness.[26] Tilting the head increases sensory noise from the otolith organs and enhances the weighting of proprioceptive input from the neck muscles, thereby increasing the demand for multisensory integration.[27–29] In line with this, laterally tilting the head while seated has been reported to disrupt communication between the visual and proprioceptive systems,[30,31] which may contribute to perceptual difficulties, and could potentially explain the increased rod deviations observed in the current study.

Group comparisons indicated that SVV deviations were similar across groups (upright and at ± 30° head tilt), whereas deviations in the DVV (upright and ±30° head tilt) and RFT (head tilt only) conditions were significantly greater in the MS group compared to the control group. Similarly, a previous study reported no significant differences in SVV outcomes between MS and control groups under ±30° head tilt.[21] In contrast, the presence of a dynamic visual reference impairs the ability to accurately align the rod with the gravitational vertical, relative to conditions involving a static reference 32. The tendency of individuals susceptible to MS to be overly influenced by dynamic visual motion cues implies a deficiency either in the otolithic and somatosensory systems or in the capacity to appropriately utilize information from these systems under conditions of pronounced sensory conflict.[33] These findings suggest that altered verticality perception in individuals with

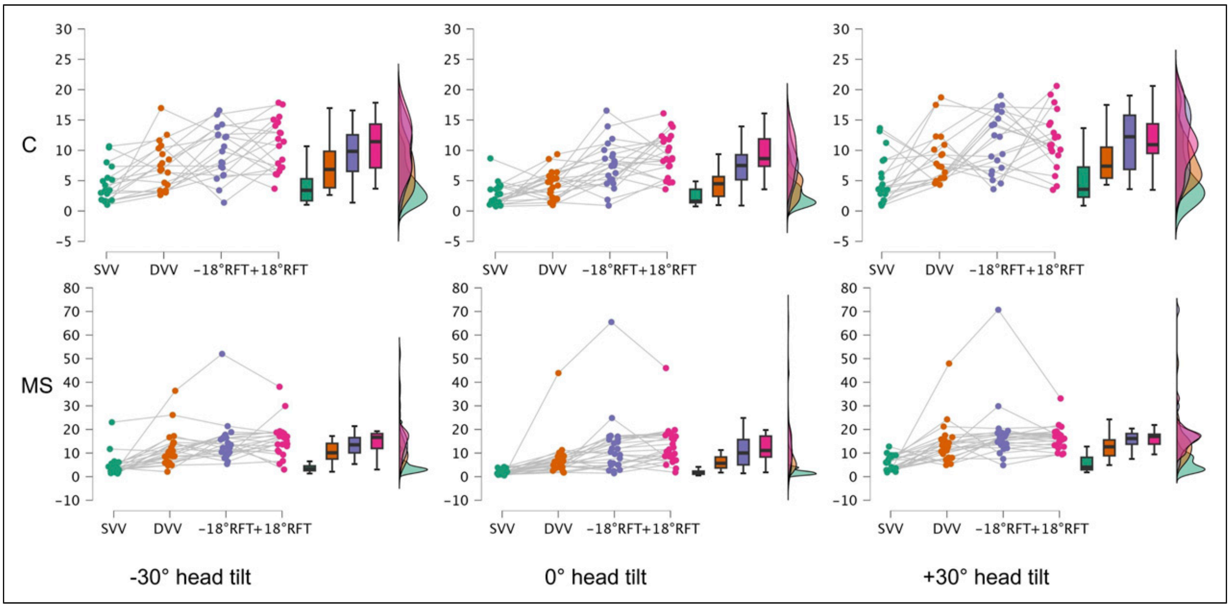

Figure 5. Comparison of test results across different head-tilt conditions (−30°, 0°, and +30°) in the control (C, top row) and motion sickness (MS, bottom row) groups. Each subplot presents individual data points, boxplots, and density distributions for static (SVV) and dynamic (DVV) subjective visual vertical, and rod-and-frame test (RFT) results at −18° and +18° frame tilt conditions. Lines connect data points from the same participant across test conditions, illustrating within-subject variability. Statistical analyses were conducted using the Friedman test.

MS may only become apparent under more demanding sensory processing conditions. Given that MS is thought to arise from mismatches in central multisensory integration, these results align with previous research highlighting disruptions in perceived verticality when the integration of visual, vestibular, and proprioceptive inputs is challenged.[24]

Peripheral and central vestibular disorders are known to trigger sensory reweighting processes that increase visual dependence.[34] In such individuals, static or dynamic visual stimuli can easily provoke symptoms related to spatial disorientation and imbalance.[34] Visual dependence has been associated with various conditions, including vestibular disorders,[35–37] neurological diseases,[38,39] and MS.[40] RFT, a tool commonly used to assess visual dependence, has been investigated in only a limited number of studies involving individuals with MS, and the findings remain inconsistent. While some studies report no significant relationship between MS susceptibility and RFT performance,[41] others indicate a meaningful correlation between RFT outcomes and the severity of MS symptoms.[42] These inconsistencies may reflect individual differences in sensory weighting strategies, the frame tilt angle, the type of testing apparatus used (e.g., VR), or the context-dependent nature of visual dependence.

Consistent with our third hypothesis, significant positive correlations were found between MSSQ scores and rod deviations in conditions involving dynamic visual input, particularly when combined with head tilt. A relationship was not observed under SVV conditions, while moderate correlations were found in some RFT conditions, especially under head tilt. Similarly, Kitajima and Sugita-Kitajima[43] found that OCR asymmetry under 30° head tilt was positively correlated with both MSSQ and Graybiel Motion Sickness scores in scuba divers, suggesting a link between otolith asymmetry and MS susceptibility. Klėgėris et al.[29] also reported greater DVV deviations in multiple sclerosis patients with a severe dizziness handicap (Dizziness Handicap Inventory score [DHI] ≥ 61) compared to those with mild (DHI <30) or moderate levels (DHI: 31–60), further highlighting the role of vestibular dysfunction in spatial disorientation. Together, these findings suggest that MS susceptibility is more likely to affect spatial perception under multisensory challenge.

Limitations

This study has several limitations. MS has been reported to be more prevalent in women than in men,[44] making it difficult to isolate the effects of gender. Similarly, in our study, the groups were not matched for gender, and the small number of male participants precluded any analysis of gender effects. Although only individuals without vestibular symptoms were included, a comprehensive vestibular evaluation was not conducted. Some MS participants had difficulty completing the dynamic test, which may have led to rushed responses and affected accuracy. Increased inter-individual variability was observed in some test conditions, particularly in the MS group. Further research with larger and more diverse samples is needed to explore the factors

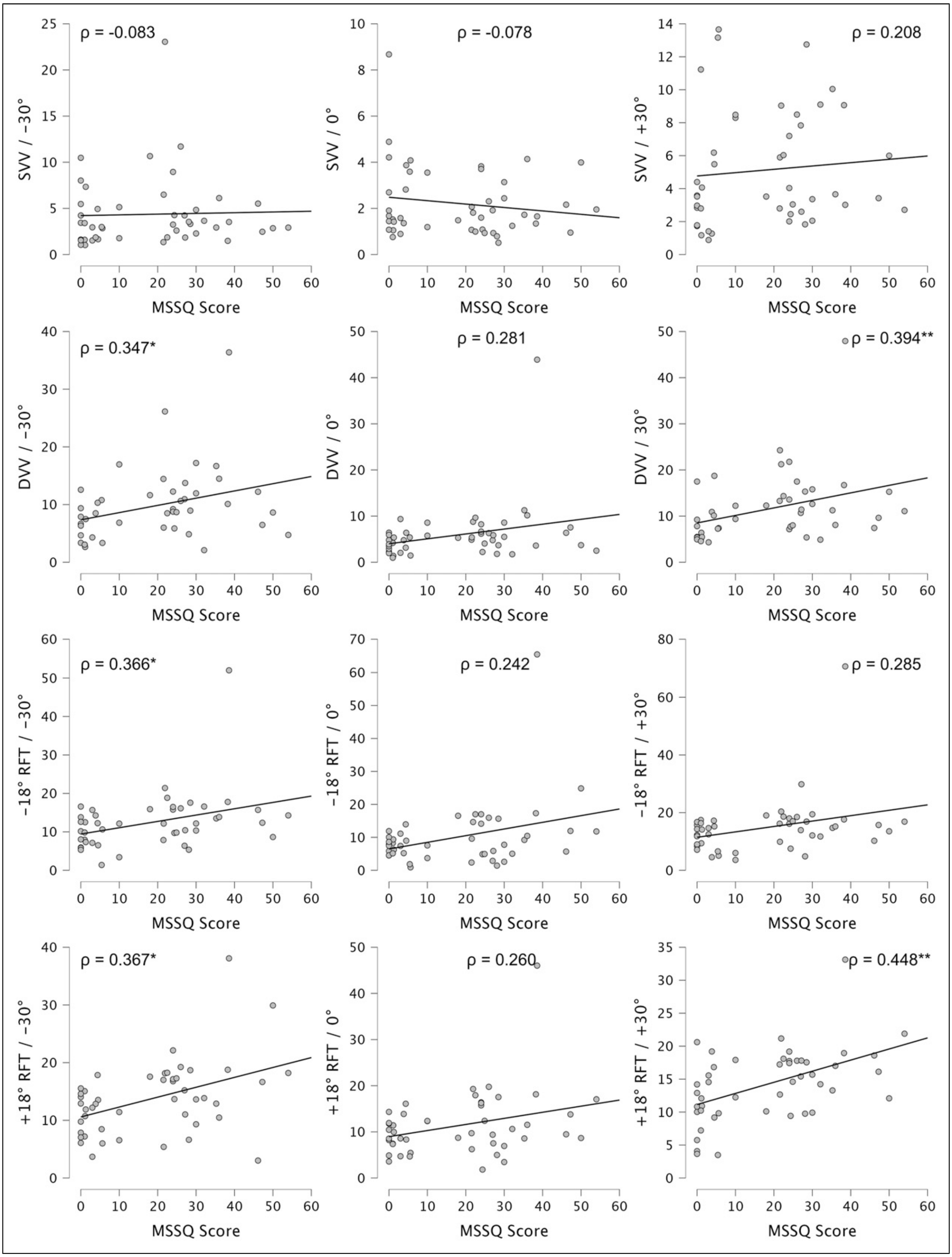

Figure 6. Spearman correlation analysis between the Motion Sickness Susceptibility Questionnaire (MSSQ) and test results across different head-tilt conditions (−30°, 0°, and +30°). Each scatter plot represents the relationship between MSSQ scores and the corresponding test outcome, with Spearman's rho (ρ) values indicating the strength and direction of the correlation. Asterisks denote statistical significance (*p < 0.05; **p < 0.01).

contributing to this variability and to identify potential predictors of greater perceptual deviations.

The study specifically assessed verticality perception, a subjective measure related to otolith function, in individuals with MS, focusing on static/dynamic SVV as well as the RFT. However, cross-validation with other objective vestibular assessments, such as OCR or vestibular evoked myogenic potentials, which also evaluate otolith function, was not performed. Future studies should investigate the relationship between subjective and objective measures of otolith function.

Finally, the asynchrony between visual and physical input caused by VR can contribute to cybersickness, leading to symptoms such as nausea, dizziness, and discomfort.[45] However, the potential effects of cybersickness on the results were not evaluated, representing another limitation of this study.

Conclusion

The present study demonstrated that individuals with MS exhibit greater deviations in verticality perception; however, the findings also suggest that the SVV test alone may be insufficient for detecting perceptual impairments in this population. The addition of a dynamic visual background (DVV) and misleading visual cues (RFT) under head-tilt conditions enhanced the sensitivity of the verticality assessment in individuals with MS. These visual manipulations appear to provide a more precise means of identifying increased visual reliance for postural orientation. Future studies could further clarify perceptual mechanisms by minimizing proprioceptive input, for example, through whole-body tilt paradigms. Overall, the findings underscore the potential clinical utility of SVV task modifications and support the need for future studies with larger patient cohorts and varying head-tilt angles to further investigate their diagnostic and rehabilitative value in individuals with MS.

Acknowledgments

We sincerely appreciate Erişçi Academy and Ms Mine Tuna for their invaluable support in providing technical insights into the VR device. Their expertise and assistance were instrumental in facilitating this study. Additionally, we would like to acknowledge undergraduate students Rümeysa K. and Cevahir Y. for their assistance during the data collection process.

ORCID iDs

Zahra Polat https://orcid.org/0000-0001-8384-4302
Sare Çankaya https://orcid.org/0000-0002-9428-6235
Burcu Deniz https://orcid.org/0000-0002-7239-215X
Mert Kılıç https://orcid.org/0000-0003-2994-6660

Ethical Approval

This study was approved by the Scientific Research Ethics Committee (Approval No: 3/27).

Consent to Participate

Informed consent was collected online via a Google Form prior to data collection.

Author Contributions

Conceptualization: Z.P. and B.D.; Methodology: Z.P., B.D., S.Ç., and M.K.; Data Collection: Z.P., B.D., M.K., and S.Ç.; Formal Analysis: Z.P., B.D, and M.K.; Visualization: Z.P., B.D., and S.Ç.; Writing – Original Draft: Z.P. and B.D.; Writing – Review & Editing: Z.P., S.Ç., and M.K.; Supervision: Z.P. All authors have read and approved the final version of the manuscript.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request. Due to participant privacy considerations, data are not publicly available.

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