Research Article

Comparative Analysis of Deviation and Response Time in Static and Dynamic Subjective Visual Vertical Among Healthy Younger and Middle-Aged Adults in an Indian Population

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Short running title: Comparative Analysis of Deviation and…

Highlights:

- Static and dynamic subjective visual vertical showed good test-retest reliability
- Dynamic SVV deviations were greater in middle-aged than in young adults
- Response times were longer in middle-aged adults across SVV conditions

Abstract

Background and Aim: The Subjective Visual Vertical (SVV) is a reliable clinical measure of an individual's ability to determine whether an object is oriented in the vertical plane, regardless of the presence of a true vertical reference. The study aimed to examine the influence of various background conditions on SVV deviation and response time, compare these outcomes between healthy younger and middle-aged adults and to measure the test-retest reliability of the SVV paradigm.

Methods: The SVV test was performed in healthy younger and middle-aged adults. A total of 100 participants were recruited for the study, 50 per group. The SVV test was administered using a standardized videonystagmography instrument (Cyclops Balance-eye device) in static and dynamic (clockwise and counterclockwise) visual background Conditions. The outcome variables, SVV deviation (°) and response time (s), were recorded under each condition. Test-retest reliability was also measured.

Results: Significant differences in SVV deviation and response time were observed across the testing conditions. Between-group analysis showed significantly greater SVV deviation under the counterclockwise and static background conditions in middle-aged adults compared with younger adults, whereas response time differed

significantly between the groups under the clockwise and counterclockwise conditions. The SVV paradigm demonstrated good test–retest reliability.
Conclusion: Dynamic SVV conditions were more sensitive than static conditions in detecting differences in SVV deviation and response time between younger and middle-aged adults, indicating subtle age-related changes in visual–vestibular processing. The SVV paradigm also demonstrated good test–retest reliability, supporting its clinical applicability.
Keywords: Subjective visual vertical; static background; dynamic condition; clockwise rotation; counterclockwise rotation, visual dependence

Introduction

The perception of spatial orientation with respect to gravity is an important aspect for maintaining appropriate posture and gait, as well as during motor activities. For all of these tasks, four sensory systems act: the vestibular, visual, interoceptive, and somatosensory systems [1]. Additionally, linear acceleration is detected by the otolith organs, which sense the head's stable position with respect to gravity [2].
The Subjective Visual Vertical (SVV) is a reliable clinical measure of an individual's ability to determine whether an object is oriented in the vertical plane, regardless of the presence of a true vertical reference. The test administration involves instructing an individual to adjust and align an illuminated light bar with respect to the individual's orientation so that it appears vertical. The amount of angular deviation perceived by an individual relative to the earth's vertical is expressed in degrees [3–5]. The functional integrity of both visual [3, 6, 7] and vestibular otolithic information [7, 8] depends upon the person's ability to align the light bar with the true vertical, and the degree to which a person relies on visual stimuli for orientation in space is termed as Visual Dependency (VD). It is based on perceptual characteristics and cognitive abilities, which are linked to psychological factors and are governed by central reweighting of multiple inputs responsible for spatial orientation [9]. It has been reported that there is significant inter-individual variability among older adults when assessing visual dependency; no significant differences have been found between older and young adults who were visually independent [10]. It can be measured using static and dynamic SVV [11]. In the static SVV condition, the individual aligns the illuminated light bar to the perceived vertical against a blank background, thereby minimizing the influence of external visual cues. In the dynamic SVV condition, the same task is performed while the visual background rotates either clockwise or counterclockwise, inducing visual motion that influences the perception of verticality. In healthy individuals, positive SVV deviation values indicate a clockwise tilt, whereas negative values indicate a counterclockwise tilt. During dynamic stimulation, the perceived verticality generally aligns with the rotating visual background, reflecting the influence of visual motion on spatial orientation. The SVV deviations obtained are sensitive indicators of peripheral or central dysfunction that can be located anywhere along the vestibular pathway from the labyrinth to the central vestibular cortex [3, 4, 7, 11].
Studies in the past compared visual dependency in older adults and younger controls [12–14]. Furthermore, Ashish et al. [15] studied SVV deviation in healthy individuals in an upright static posture and reported static and dynamic deviations in the Indian population among young and middle-aged adults. However, there is a dearth of studies on SVV response time across three stimulus conditions (clockwise rotation, counterclockwise rotation and blank background) in different age groups in the Indian population. Additionally, most previous studies lack the test-retest reliability of SVV measures across different conditions, limiting their consistency and accuracy across clinical contexts. Therefore, the current study aimed to examine the influence of various background conditions on SVV deviation (°) and response time (s) in healthy younger and middle-aged adults and to measure the test-retest reliability of the SVV paradigm.

Methods

The study was a prospective, cross-sectional single-centre study on healthy adults. Based on pilot study data, G*Power analysis showed a required sample size of 16-20 participants. To increase strength and account for variability across test conditions, 100 participants were recruited. This sample size yielded an achieved power (1-β) greater than 0.95 at α=0.05. The study participants were further categorised into two groups: Group I, which consists of 50 healthy young adults (21 to 40 years, mean age 22.74±2.38), whereas. Group II, consisting of 50 participants, included healthy middle-aged adults (41–60 years, mean age 49.8±6.65). These age ranges are consistent with standard classifications of adult developmental stages described in lifespan development literature [16].

The test procedure began with a standardized case history to assess participants' suitability for inclusion in the testing, followed by an otoscopic examination to confirm a bilateral intact tympanic membrane and absence of abnormality in the external auditory canal. Routine audiological evaluation included pure-tone air-conduction audiometry from 250 Hz to 8000 Hz and normal bone-conduction findings from 250 Hz to 4000 Hz. Bilateral 'A' type tympanometry with acoustic reflexes presents at 500 Hz to 4000 Hz. Normal Findings on bedside vestibular tests were defined as the ability to complete the Romberg and sharpened Romberg tests without instability, completion of the tandem gait test with fewer than two out-of-line steps in ten consecutive tandem steps, and a Fukuda stepping test showing an angular deviation within the normal range (≤30°).

Participants with a history of otologic, neurological problems, giddiness, mental illness, alcohol consumption, smoking, diabetes, hypertension, cardiovascular disease, consistent headache, ototoxicity, exposure to loud sounds and reported illness on the day of testing were excluded from the study.

Subjective visual vertical test procedure

All participants underwent SVV testing using a standardized videonystagmography instrument (BalanceEye, Cyclops MedTech Private Limited India) performed by a trained audiologist. Before the SVV testing, all participants were provided with tips before taking the test to ensure appropriate testing conditions and reliable data recording.

They were instructed to avoid wearing contact lenses during the test, but may bring eyeglasses if needed. Refrain from consuming caffeine (e.g. coffee, tea, cola) after midnight before the test. Abstain from consuming alcoholic beverages at least 48 hours prior to the test. Participants were instructed to avoid wearing eye makeup during the test [17]. Furthermore, participants were reassured that the test is non-invasive and benign. The participant's task was to adjust a laser line to align with the true vertical without any other cues. The SVV evaluation began with system calibration before each testing session to ensure measurement accuracy. The assessment protocol began with the static background condition, followed by dynamic clockwise rotation and subsequently dynamic counterclockwise rotation. The SVV testing was conducted in a quiet, well-controlled room to minimize any visual distractions and ensure appropriate recording of eye movements. Using standardized equipment, the goggles were fitted accurately, including an infrared camera for recording the precise deviation characteristics. Participants were seated upright at approximately 2 meters from the viewing screen, with their eyes aligned with the center of the monitor. The viewing distance and seating position were kept constant for all participants throughout the testing procedure to ensure measurement consistency. The rotation was participant-controlled; therefore, a fixed rotation speed (°/s) and rotation range were not predetermined but varied according to the participants' responses. Three trials were completed for each test condition, with a chair and a controlled testing setup, and appropriate lighting conditions were ensured. Participants were provided with a handheld response remote to precisely align perceived vertical alignment. A total of three recordings were taken in each condition, and the average deviation (°) and time (s) taken i.e. response time were recorded for further statistical analysis across the three conditions: clockwise, counterclockwise, and static i.e. blank background.

Test-retest reliability

Test-retest reliability was assessed in 20 participants, including 10 participants from the 21-40 age group (mean age 22.74±2.38) and 10 from the 41-60 age group (mean age 49.8±6.65), using a simple random sampling method. SVV deviation (°) and response time (s) measurements were repeated across static background, clockwise-rotating, and counterclockwise-rotating visual background conditions following an interval of one week to minimize potential recall and learning effects while ensuring clinical stability of the measured parameters. The testing protocol, instructions, instrument setup and trained clinician were kept consistent across both sessions.

Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) software version 26.0 (IBM Corp., Armonk, NY, USA). Graphs and figures were generated using GraphPad Prism version 11.0.1 (GraphPad Software, Inc., San Diego, CA, USA). The Shapiro-Wilk test for normality indicated a non-normal distribution. Hence, non-parametric statistical tests were employed. The Friedman test was used to assess differences in SVV deviation (°) and response time (s) across visual background conditions, followed by Bonferroni-adjusted Wilcoxon signed-rank tests for pairwise comparisons. Age-group comparisons were observed using the Mann-Whitney U test. Test-retest reliability was assessed using the Interclass Correlation Coefficient (ICC), and Bland-Altman plots were used to assess agreement, mean bias, and limits of agreement between sessions. Statistical significance was considered at $p<0.05$.

Results

The current study highlights the effect of test condition on SVV deviation (°) and response time. The data did not fulfil the assumptions of normality ($p<0.05$). Hence, a nonparametric test was used to analyse data across various SVV conditions.

Subjective visual vertical deviation across visual conditions in younger and middle-aged adults

The SVV deviation (°) was assessed in static and dynamic conditions. In the static condition, SVV was assessed in static background; in the dynamic condition, it was tested in clockwise and counterclockwise. The mean, median and range of deviation (°) across visual conditions in younger and middle -aged adults are depicted in Table 1.

Because the data were not normally distributed, non-parametric tests were used for analysis. Table 1 shows the SVV deviation (°) across various visual background conditions in younger and middle-aged adults. A statistically significant difference was observed across the three conditions, $\chi^2(2)=10.155$, $p=0.006$. Post hoc analysis with Bonferroni correction revealed a statistically significant difference between the counterclockwise and static background conditions ($p=0.009$). However, no significant differences were observed between static background and clockwise condition ($p=0.147$) and clockwise and counterclockwise conditions ($p=0.084$).

Between-group comparisons showed no significant difference between the two groups for clockwise deviation (°) ($p=0.211$), whereas significant differences were noted for counterclockwise ($p=0.035$) and static background ($p=0.029$).

Subjective visual vertical response time across visual conditions in younger and middle-aged adults

The mean, median and range of response time across visual conditions in younger and middle-aged adults are depicted in Table 2.

Table 2 shows SVV response time (s) across various visual background conditions in younger and middle-aged adults. A statistically significant difference across the three conditions, $\chi^2(2)=16.959$, $p<0.001$. Post hoc analysis with Bonferroni correction revealed a statistically significant difference between the clockwise and static background ($p<0.001$) and between the counterclockwise and static background conditions ($p=0.004$). However, no significant differences were observed between the clockwise condition and the counterclockwise condition ($p=0.223$)

Between-group comparisons showed significant differences between younger and middle-aged adults for clockwise deviation ($p=0.003$) and counterclockwise ($p=0.001$). However, no significant difference was observed for the static background condition ($p=0.130$)

Test-retest reliability analysis

A test-retest analysis was performed to assess the consistency and agreement of SVV measurements across three conditions. Reliability was measured using the ICC analysis, while agreement between measurements was assessed using the Bland-Altman Plot analysis.

Interclass correlation coefficient analysis

ICC analysis was performed separately for the Static Background (SB), Clockwise (CW), and Counterclockwise (CCW) conditions to assess the test-retest reliability of SVV deviation (°) and response time (s) measurements. For SVV deviation, excellent test-retest reliability was observed for SB (ICC=0.926, $p<0.001$), whereas good test-retest reliability was observed for CW (ICC=0.895, $p<0.001$) and CCW (ICC=0.846, $p<0.001$). Similarly, SVV response time measurements demonstrated good test-retest reliability was observed for CW (ICC=0.892, $p<0.001$) and CCW (ICC=0.830, $p<0.001$). While moderate-to good reliability was observed for SB (ICC=0.766, $p<0.001$) conditions.

Bland-Altman agreement analysis

Bland-Altman analysis demonstrated minimal systematic bias and satisfactory agreement across all visual background conditions for SVV deviation and response time measurements, as shown in Figures 1 and 2.

Discussion

The current study investigated the effects of static and dynamic visual backgrounds on SVV deviation (°) and response time (s) in healthy younger and middle-aged adults. The research findings revealed a significant difference in deviation (°) and response time (s) across the three SVV conditions. Good test-retest reliability was also observed. static background findings were±2° for the 20 to 40-year age group (mean age 22.74±2.38), whereas they were -3° to 2° for the 41 to 60-year age group (mean age 49.8±6.65).

Static SVV deviation findings were within normal limits, suggesting preserved otolith-mediated perception of verticality in both age groups [8]. Compared with the static background condition, dynamic visual backgrounds produced greater SVV deviation. For the clockwise condition, ±2° for the 21 to 40-year age group (mean age 22.74±2.38) and -1° to 2° for the 41 to 60-year age group. For the counterclockwise condition, it was±3° for the 21 to 40-year age group (mean age 22.74±2.38), whereas it was -2 to 3° for the 41 to 60-year age group (mean age 49.8±6.65). These findings may be attributed to the fact that rotary visual flow creates an illusion of self-motion, thereby biasing the perception of gravitational verticality toward the direction of visual motion [18]. Furthermore, a similar magnitude of deviation was noted for the dynamic condition, suggesting a symmetrical influence of dynamic visual input on verticality perception. These findings suggest that the visual system processes the two rotational directions comparably, leading to equivalent alterations in perceived verticality [19]. The SVV response time was varied among static and dynamic conditions. A significant difference was observed between the SB and CW conditions and the SB and CCW conditions.

This could be due to greater reliance on visual background information, which may increase susceptibility to visual illusions of motion, especially during exposure to rotating backgrounds. This can further alter the vestibular integration process and alter the perceived orientation of verticality towards the direction of visual motion [18-21].

Group comparison revealed alterations in dynamic visual background conditions, with significant differences noted during the counterclockwise condition. The static background condition remained stable; these findings may reflect subtle alterations in visual-vestibular interaction [9]. On the other hand, response time showed a significant difference during the dynamic background conditions (clockwise and counterclockwise) compared to the stable background. Dynamic visual stimulation requires continuous integration of moving visual cues with vestibular and somatosensory information to maintain accurate perception of verticality. The presence of rotating visual backgrounds may therefore increase perceptual and attentional processing demands, resulting in prolonged alignment response times [18, 19, 22].

In the present study, significantly longer response times were observed only under the dynamic visual background conditions, which impose greater visual-vestibular conflict and increase cognitive processing demands. This finding suggests that age-related differences in processing speed become more apparent when the task requires integration of conflicting sensory inputs, whereas the static condition may not be sufficiently demanding to reveal such differences.

Test-retest reliability was satisfactory for SVV deviations across SB, CW, and CCW. The ICC values indicate excellent reliability for the static background condition, indicating high consistency of vertical perception in the bank background condition. Conversely, slightly less, i.e. good reliability was noted for clockwise and counterclockwise dynamic conditions. This could be due to the increased complexity of visuo-vestibular integration under dynamic visual backgrounds. Similarly, good test-retest reliability was observed for SVV response time across CW and CCW conditions, indicating consistent participant responses across repeated trials, even in visually challenging background conditions. On the other hand, moderate-to-good reliability was noted for the static background condition. This could be due to variability in decision-making, attentional processing, and motor response timing during the test [23]. Nevertheless, the overall reliability of both SVV deviation (°) and response time (s) measures supports their stability and potential applicability for assessing verticality perception and visual dependency. Our findings are in line with previous research [11, 23-25]. According to previous literature, SVV is a reliable measure of otolith function and visuospatial orientation. Moreover, supporting its clinical applicability in vestibular assessment and long-term monitoring [26, 27].

The current study has a few limitations, such as its focus on young and middle-aged adults, which limits the clinical applicability of its findings to older adults, where visual dependency and sensory reweighting may be more pronounced. Future studies should include older age groups to better understand age-related changes in visual dependency and sensory integration across the lifespan. The SVV performance is based on subjective vertical perception. Incorporating objective vestibular assessments, such as the video head impulse test, vestibular evoked myogenic potential, and dynamic visual acuity, could help delineate the relative contributions of the visual and vestibular systems.

Conclusion
The findings of the present study suggest that dynamic visual background conditions significantly influence Subjective Visual Vertical (SVV) performance, particularly response time, in younger and middle-aged adults. Dynamic SVV paradigms appeared more sensitive than static conditions in revealing subtle alterations in visual–vestibular interaction and visual dependency. Furthermore, the SVV paradigm's satisfactory reliability highlights its potential as a clinically applicable tool for evaluating verticality perception under dynamic visual conditions.

Ethical Considerations

Compliance with ethical guidelines
The study was conducted with prior Institutional Ethical Permission Letter, reference no. SVIEC/ON/DASLP/BNPG24/Feb/25/03, dated 04/02/2025. All participants provided informed consent in both verbal and written form and confirmed their willingness to participate in the study.

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Authors' contributions
AB: Conceptualization, methodology, investigation, data curation, writing-original draft; SSB: Conceptualization, methodology, writing-review and editing, supervision, project administration.

Conflict of interest
No potential conflict of interest relevant to this article was reported.

Data availability statement
The data of this study are available from the corresponding author upon reasonable request.

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Table 1. Mean, standard deviations, median and range of deviation (°) across visual conditions in younger and middle-aged adults (n=50 per group)

Visual condition	Age group (years)	Mean±SD	Median	Minimum	Maximum
Static background	21–40	–0.08±0.96	0.00	–2	2
	41–60	0.34±1.11	0.00	–3	2
Clockwise	21–40	0.18±0.91	0.00	–2	2
	41–60	0.42±0.85	0.00	–1	2
Counterclockwise	21–40	–0.46±1.50	–1.00	–3	3
	41–60	0.16±1.34	1.00	–2	3

Subjective visual vertical deviation is expressed in degrees (°), representing angular deviation from true vertical. Positive values denote clockwise deviation, and negative values denote counterclockwise deviation.

Table 2. Mean, standard deviations, median and range of response time (s) across visual conditions in younger and middle-aged adults (n=50 per group)

Visual condition	Age group (years)	Mean±SD	Median	Minimum	Maximum
Static background	21–40	9.02±3.23	8.50	4	17
	41–60	9.80±2.21	9.50	7	16
Clockwise	21–40	9.78±3.24	9.50	5	19
	41–60	11.58±2.76	11.00	7	20
Counterclockwise	21–40	9.28±2.63	9.00	4	16
	41–60	11.08±2.56	11.00	7	21

Response time is expressed in (s), representing the time taken to complete the task.

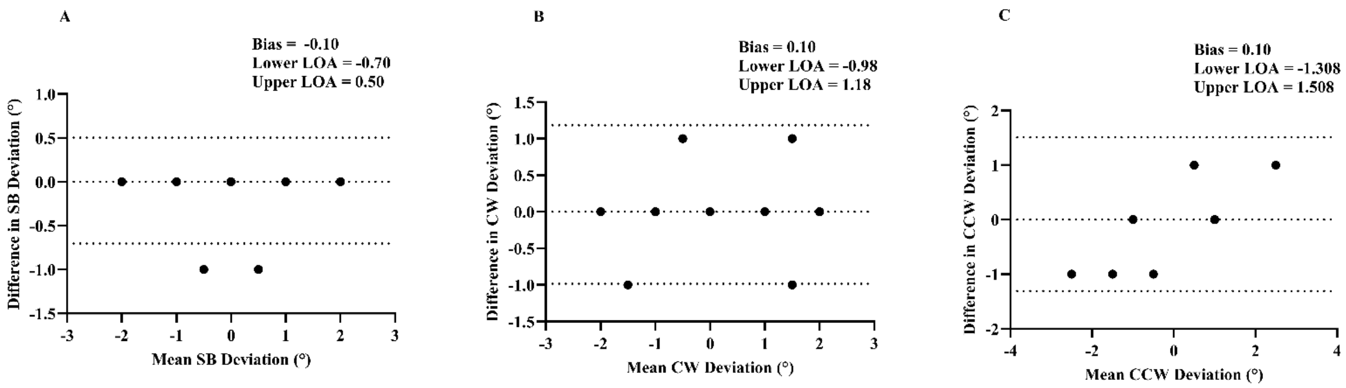

Figure 1. Bland-Altman plots illustrating agreement between test and retest subjective visual vertical deviation (°) measurements under A) static background (SB), B) clockwise (CW), and C) counterclockwise (CCW) conditions. Each point represents one participant (n=20)

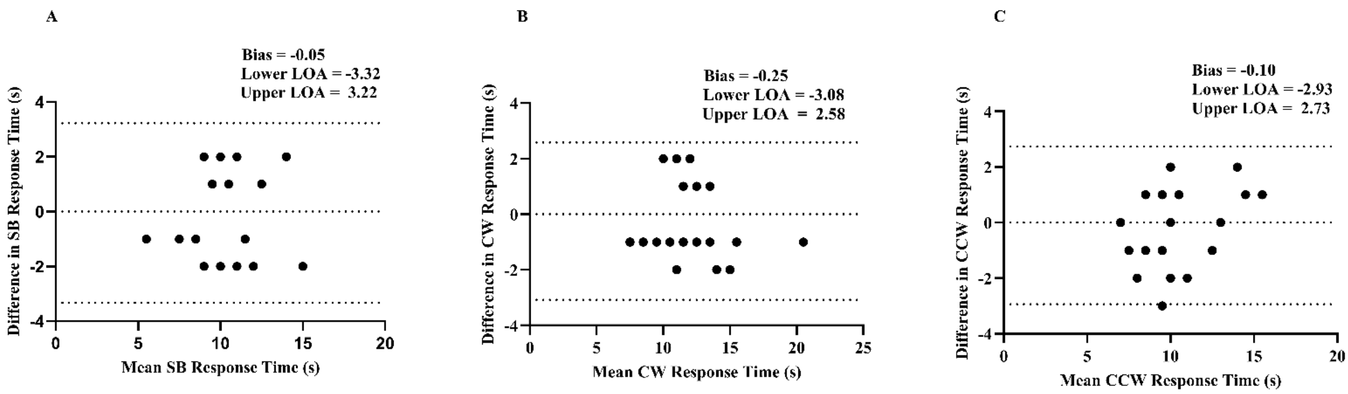

Figure 2. Bland-Altman plots illustrating agreement between test and retest subjective visual vertical response time (s) measurements under A) static background SB, B) clockwise (CW), and C) counterclockwise (CCW) conditions. Each point represents one participant (n=20)