Normative Data for the Subjective Visual Vertical Test during Centrifugation

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Faith W. Akin*†
Owen D. Murnane*†
Amber Pearson*
Stephanie Byrd*
J. Kip Kelly*

Abstract

Background: The otoliths act as gravito-inertial force sensors and contribute to the perception of spatial orientation. The perception of gravitational vertical can be assessed by asking a subject to adjust a light bar to the vertical. Prior to clinical use of the SVV (subjective visual vertical) test, normative data and test-retest reliability must be established.

Purpose: To obtain normative data and determine the test-retest reliability for the SVV test performed in static and dynamic test conditions.

Research Design: A descriptive design was used to obtain normative data.

Study Sample: Twenty-four young adults with no history of neurological disease, middle-ear pathology, open or closed head injury, cervical injury, or audiovestibular disorder participated in the study.

Data Collection and Analysis: The SVV angle was measured in the static position and in three dynamic conditions: (1) on-axis clockwise (CW) rotation, (2) off-axis CW rotation of right ear, and (3) off-axis CW rotation of left ear.

Results: In young healthy individuals, the SVV was <2° for static and on-axis rotation, and shifted up to 11° during unilateral centrifugation. Test-retest reliability of the SVV was good for all test conditions.

Conclusions: The normative data obtained in this study may be useful in identifying patients with chronic utricular dysfunction. We recommend the use of difference angles (on-axis SVV – off-axis SVV) to remove baseline bias and decrease the variability of the SVV angles for the off-axis conditions.

Key Words: Saccule and utricle, subjective visual vertical, vestibular function tests

Abbreviations: CCW = counterclockwise; CW = clockwise; GIF = gravito-inertial force; SVV = subjective visual vertical; VOR = vestibulo-ocular reflex

The otolith organs, comprised of the saccule and the utricle, transduce information about linear acceleration of the head and the position of the head relative to gravity (head tilt), and contribute to postural stability. In an upright position, the saccules are positioned vertically and sense linear acceleration in the vertical plane. In contrast, the utricles are positioned horizontally and sense linear acceleration in the lateral plane. The otoliths act as gravito-inertial force (GIF) sensors and contribute to the perception of spatial orientation. The perception of gravitational vertical, which is also called true vertical (0°), can be assessed

*James H. Quillen VA Medical Center, Mountain Home, TN; †Department of Audiology and Speech Language Pathology, East Tennessee State University

Faith W. Akin, Audiology (126), VAMC, Mountain Home, TN 37684; Phone: 423-926-1171, ext. 7376; Fax: 423-979-3403; E-mail: Faith.akin@va.gov

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by asking an individual either to adjust his/her body position to the vertical or horizontal (postural vertical or horizontal) or to adjust a light bar to the vertical or horizontal (subjective visual vertical or horizontal) (see Figure 1). Subjective visual vertical (SVV) is the angle between the adjusted light bar (perceptual vertical) and true vertical. Numerous studies have determined that the SVV in healthy individuals in an upright static position does not deviate more than ±2.5° from true vertical (Neal, 1926; Witkin and Asch, 1948; Böhmer and Rickenmann, 1995; Tribukait et al., 1996).

Static SVV is sensitive to acute vestibular loss; however, patients with chronic unilateral vestibular loss cannot be distinguished by their SVV from normal subjects unless sophisticated nonphysiological stimulation techniques are used to stimulate the otolith organs (Böhmer and Mast, 1999). Commercially available rotational chairs can be used to stimulate the otoliths during the SVV test (dynamic SVV test) by rotating an individual on axis (center) to stimulate both otoliths or by moving the chair laterally and rotating an individual off axis to stimulate one otolith organ at a time.

On-axis (center) rotation is used routinely to stimulate the horizontal semicircular canals. Because the horizontal semicircular canals sense angular acceleration in the lateral plane, sinusoidal (harmonic) acceleration has been used during rotational testing to measure the vestibulo-ocular reflex (VOR) response for clinical assessment of semicircular canal function. During constant velocity rotation, however, the VOR response from the horizontal semicircular canals extinguishes. Because the utricles are positioned 3.5–4 cm from midline (Nowé et al., 2003), constant velocity on-axis rotation with the head positioned upright also stimulates the otolith organs (see left panel of Figure 2). Specifically, constant on-axis rotation creates a centrifugal force (or linear acceleration) that activates the utricular maculae (sensory cells of the utricle) bilaterally. It is presumed that the utricles are stimulated rather than the saccules because the linear acceleration (centrifugal force) along the interaural axis corresponds to the primary axis of the utricular maculae. Because the utricles are centrifuged bilaterally, they receive equal GIF resulting in no shift in the perception of SVV tilt if both utricles function similarly.

Off-axis (eccentric) rotation or unilateral centrifugation was first described as a unilateral test of utricular function by Wetzig et al (1990). To perform this test (shown in the right panel of Figure 2), the subject is seated upright and the chair is displaced laterally so that the test ear is positioned off axis (typically 7–8 cm) and the non-test ear is positioned on axis. The chair is rotated at a constant velocity that extinguishes the horizontal semicircular canal VOR response and creates a centrifugal force that stimulates the utricle positioned off axis. Thus, in contrast to on-axis rotation, which results in bilateral centrifugation (stimulates both utricles), off-axis rotation stimulates only the test ear with centrifugal force (unilateral centrifugation) and results in a perceptual tilt away from the test ear.

The inertia (or centrifugation) acting on the otolith organs during on- or off-axis rotational testing is dependent on the speed at which the chair rotates (angular velocity) and the position of the utricles relative to the axis of rotation. The centrifugal force can be determined using the following formula:

\[ g = \frac{ro^2}{G} \]

in which \( g \) = radial g force, \( \omega \) = angular velocity, and \( r \) = the radial position of the utricle from the center of rotation. In addition to the centrifugal force, the utricles sense gravity (980.7 cm/sec\(^2\) or 1 g) as a constant force acting on the utricles. The GIF, therefore, is the combined force of centrifugation and gravity. The GIF can be used to predict the perceived gravity angle away from earth vertical (90°), which contributes to the SVV. For example, with no centrifugation, the perceived gravity angle is 90° and the SVV is 0° (shown in the right side of Figure 2 for the left ear positioned on axis).

During on-axis (center) rotation, both ears are positioned 3.5 cm from the axis of rotation and rotated at a constant angular velocity (e.g., 300°/sec) (see head on left side of Figure 2). Thus, both utricles receive a centrifugal (lateral) force of 96.0 cm/sec\(^2\) (0.098 g) and GIF of 985.4 cm/sec\(^2\) (1.005 g) resulting in perceived gravity angles of 6° from vertical (90°–6° = 84°) on both sides. In a healthy individual, the perceived gravity angles are cancelled across sides resulting in no perception of tilt (SVV = 0°). In contrast, when the chair is positioned off axis the test ear is placed at 7 cm from the axis of rotation and the non-test ear is...
positioned at 0 cm from the axis of rotation (see head on right side of Figure 2). If the constant angular velocity is 300°/sec, then the test ear (positioned off axis) receives a centrifugal force of 191.9 cm/sec² (0.196 g) and GIF of 999.3 cm/sec² (1.019 g), and the nontest ear (positioned on-axis) receives 0 cm/sec² (0 g) centrifugal force and GIF of 980.7 cm/sec² (1 g). The perceived gravity angle is 11° away from earth vertical (90° – 11° = 79°) on the right (test) side and 0° (90° – 0° = 90°) on the left (nontest) side.

Although normative data are available for the SVV test in the static condition, few data are published for SVV in the dynamic conditions (i.e., centrifugation). Furthermore, test-retest reliability for static SVV is good in normal controls (Gómez García and Jáuregui-Renaud, 2003), but the test-retest reliability of the SVV in the dynamic conditions is unknown. Prior to clinical use of the SVV test, normative data and test-retest reliability must be established. The purpose of this study was to obtain normative data in young individuals and determine the test-retest reliability for the SVV test performed in static and dynamic conditions.

METHODS

Twenty-four young individuals (2 males, 22 females; mean age = 24 yr, SD = 2 yr) with no history of neurological disease, middle-ear pathology, open or closed head injury, cervical injury, or audiovestibular disorder participated in the study. This study was approved by the institutional review board at East Tennessee State University/Veterans Affairs Medical Center, and all individuals signed an informed consent form prior to participation in the study. The study participants were given nominal payment for their time.

Procedures

To establish normative data for the SVV test, the SVV angle was obtained in the static position and in three dynamic conditions: (1) on-axis clockwise (CW) rotation, (2) off-axis CW rotation of right ear, and (3) off-axis CW rotation of left ear. To determine the effect of rotational direction on the SVV angle, the procedure was repeated for the dynamic conditions in a second session using a counterclockwise (CCW) rotation. To determine test-retest reliability of the SVV test, the procedure was repeated for the dynamic conditions in the CW direction following a 1–2 wk interval. For each test session, the SVV was obtained for the static condition first, and the test order was randomized for the three dynamic SVV conditions. A rest period up to 5 min was provided between each test condition, and each test session lasted approximately 30 min. An intercom system was used for communication between the subject and the investigator.
Measurement of SVV

The participants were positioned upright in a darkened booth (Micromedical System 2000 rotational chair) and instructed to turn a dial to orient vertically an SVV LED bar positioned at eye level and 35 cm from the subject during four test conditions (see Figure 1): (1) static, (2) on-axis rotation, (3) off-axis rotation of right ear, and (4) off-axis rotation of left ear. The SVV angles were measured five times for each test condition, and the SVV angles were averaged to find the mean absolute SVV angles. The starting position of the light bar was randomized prior to each trial.

Static

Prior to the dynamic SVV measurements, SVV was measured in the static position. Each participant was placed in an upright, sitting position, the head was strapped to a head support, and the waist was secured in the darkened rotational chair booth. The chair remained stationary, and the SVV was measured according to the above procedure.

On-Axis Rotation (Bilateral Centrifugation)

Each participant was placed on-axis in an upright, sitting position and secured in the darkened rotational chair booth (see left head in Figure 2). The forehead, shoulders, waist, and ankles were secured to the rotational chair and the SVV was measured during bilateral centrifugation (constant velocity rotation). The following is a description of the sequence of events for the on-axis rotation: the chair accelerated clockwise from 0°/sec to 300°/sec in 60 sec (acceleration = 5°/sec²) and then rotated in the clockwise direction at a constant velocity (300°/sec) for 60 sec. Five SVV angles were measured during a 30 sec constant velocity rotation (300°/sec) period according to the procedure described previously. Following the five SVV measurements, the chair was decelerated from 300°/sec to 0°/sec in 60 sec (deceleration = 5°/sec²). The participants were instructed to close their eyes during the acceleration and deceleration periods to minimize the opportunity for nausea.

Off-Axis Rotation (Unilateral Centrifugation)

Each participant was placed in an upright, sitting position with the test ear positioned 7–8 cm off-axis and the nontest ear positioned on-axis (see right head in Figure 2). The forehead, shoulders, waist, and ankles were secured to the rotational chair, and the SVV was measured during unilateral centrifugation in the darkened booth. The sequence of events for the off-axis rotation conditions were the same as the on-axis rotation condition previously described. The procedure was repeated with the opposite ear placed in the off-axis position and the nontest ear positioned on-axis according to the randomized test order for each participant.

The data are shown in the results as the absolute SVV values and the difference angles. The absolute SVV values represent the mean deviations to both sides with positive values indicating deviations of the upper pole of the light bar to the right (as seen by the subject), and negative values indicating deviations of the upper pole of the light bar to the left. The difference angles were calculated as: (1) the mean off-axis right SVV minus the mean on-axis SVV and (2) the mean off-axis left SVV minus the mean on-axis SVV.

At the completion of the study, the participants were asked to complete a survey regarding the anxiety, discomfort, and test difficulty level of the dynamic SVV conditions. A five-level Likert scale was used to measure the responses to the following statements: (1) this test caused me anxiety, (2) this test caused me discomfort, and (3) this test was difficult. The response choices were (1) strongly disagree, (2) disagree, (3) neutral, (4) agree, or (5) strongly agree.

RESULTS

The box plots in Figure 3 show the normative data for the four SVV test conditions and the difference angles (off-axis SVV – on-axis SVV). The box edges represent the 25th and 75th percentiles, and the error bars represent the 10th and 90th percentiles. The mean SVV values are represented by the dashed line within each box. The mean SVV angles were 0° (SD = 1.2°) and 1° (SD = 1.5°) for the static and on-axis conditions, respectively. Most participants shifted the SVV toward the nontest ear during off-axis rotation (unilateral centrifugation), and the SVV angles ranged from 0 to −8° for the offset right condition and from 0 to 11° for offset left condition (offset right: mean = −3°, SD = 2.1°; offset left: mean = 5°, SD = 2.6°). The mean difference SVV angles were 4° (SD = 2.0°) for off-axis right and 4° (SD = 1.9°) for off-axis left. The variability of the absolute off-axis SVV angles was slightly greater than the variability of the difference SVV angles.

To determine if the direction of rotation affected the SVV angle, the SVV was obtained during CCW rotation during the second test session. The left panel of Figure 4 shows a bivariate plot of the individual absolute SVV data for CCW rotation as a function of the absolute SVV for CW rotation for the on-axis rotation, the off-axis right ear, and the off-axis left ear conditions. The correlation analysis indicated a good positive relation between the SVV angles obtained with CW rotation and CCW rotation (R² = 0.72, p < 0.001), and the slope of the regression, 0.84, approaches unity, which
indicates a near one-to-one relation between the two variables. The right panel of Figure 4 shows a bivariate plot of the SVV difference angles for CCW rotation as a function of SVV difference angles for CW rotation for the off-axis right and the off-axis left conditions. The correlation analysis indicated a good positive relation between the SVV difference angles obtained with CW rotation and CCW rotation (R^2 = 0.75, p < 0.001), and the slope of the regression approaches unity. These results suggest that the direction of the chair rotation (clockwise or counterclockwise) did not change the direction or the magnitude of the SVV angle.

To determine test-retest reliability, the SVV during CW rotation was repeated during a third test session. The left panel of Figure 5 shows a bivariate plot of the individual absolute SVV angles for the static, the on-axis rotation, the off-axis right, and the off-axis left conditions for Session 1 as a function of the absolute angles for Session 2. The correlation analysis indicated good test-retest reliability for the absolute SVV angles (R^2 = 0.68, p < 0.0001), and the slope of the regression approaches unity. The right panel of Figure 5 shows a bivariate plot of the SVV difference angles for the off-axis right and the off-axis left conditions in Session 1.

Figure 3. Box plots showing normative data for the four SVV test conditions and the difference angles (off-axis SVV – on-axis SVV). The box edges represent the 25th and 75th percentiles; the error bars represent the 10th and 90th percentiles. The median is represented by the thin solid line within each box. Absence of a thin solid line within a box indicated the median is equal to a box edge. The mean is represented by the dashed line within each box. The mean data were as follows: static (0°), on axis (1°), off-axis right (−3°), off-axis left (5°), off-axis right difference (Δ) angle (−4°) and off-axis left difference (Δ) angle (4°).

Figure 4. Left panel: Bivariate plot of individual absolute SVV data for CCW rotation (abscissa) versus CW rotation (ordinate) of the following SVV test conditions: on-axis rotation (+), off-axis rotation of right ear (triangles), and off-axis rotation of left ear (circles). Right panel: Bivariate plot of SVV difference angles (off-axis SVV – on-axis SVV) for CCW rotation (abscissa) vs. CW rotation (ordinate) for the off-axis right (triangles) and the off-axis left (circles) conditions.
as a function of the SVV difference angles for Session 2. The correlation analysis indicated good test-retest reliability for the difference angles ($R^2 = 0.78$, $p < 0.0001$), and the slope of the regression approaches unity.

Table 1 lists the responses obtained from the participants regarding the anxiety, discomfort, and test difficulty levels experienced with the dynamic SVV tests. Most subjects ($n = 20$) disagreed that the dynamic SVV conditions (on-axis and off-axis rotation) caused anxiety or discomfort, and all but one subject indicated that the dynamic SVV tests were not difficult to perform.

**DISCUSSION**

The SVV test has been proposed as a clinical test of otolith function. Specifically, the SVV test during bilateral and unilateral centrifugation has been used to assess utricular function. The purpose of this study was to obtain normative data for the SVV test in static and dynamic conditions and determine the test-retest reliability in healthy young individuals.

In the present study, the SVV angle obtained in the static, upright position was $0^\circ$ (SD = 1.2), which is consistent with data from previous studies (Witkin and Asch, 1948; Böhm and Rickenmann, 1995; Tribukait et al., 1996). The SVV is a spatial orientation task that depends on multimodal sensory input. Psychologists have used the SVV as a psychophysical measure of spatial orientation for many years (e.g., Neal, 1926; Witkin and Asch, 1948); however, Friedmann (1970) was the first to show that the SVV is affected by loss of input to the peripheral vestibular system. More recently, Böhm and colleagues demonstrated that the static SVV shifts with the upper pole of the light bar toward the lesioned side in patients following vestibular nerve section. During acute vestibulopathy, patients may tilt the SVV toward the affected side by up to $20^\circ$ (Böhm and Rickenmann, 1995). Böhm and Mast (1999) theorized that otolith organs in both inner ears act as an antagonistic push-pull mechanism when determining the SVV. A unilateral vestibular disturbance causes an imbalance in the neuronal resting discharge, and the otolith organs of the contralateral ear “push” the SVV up to $20^\circ$ to the opposite, diseased side. The offset of the SVV may be owing to ocular torsion (a torsional deviation of the eyes) caused by the ocular tilt reaction (a postural synkinesis consisting of head tilt, conjugate ocular torsion, and skew deviation toward the same side) (Halmagyi and Curthoys, 2007). Although the mechanism of ocular torsion is not fully understood, conjugate ocular tilt reaction of the otolith system is considered analogous to spontaneous nystagmus of the semicircular canal system (Halmagyi and Curthoys, 2007). Once vestibular adaptation is complete (in weeks to months) the SVV approaches normal ($\pm 2.5^\circ$ from true vertical) (Böhm and Rickenmann, 1995; Vibert

![Figure 5](image_url)
Numerous studies have demonstrated that patients with brainstem lesions or cerebellar lesions can show ocular torsion and offset of the static SVV (e.g., Friedmann, 1970; Dieterich and Brandt, 1993; Mossman and Halmagyi, 1997). For example, lower brainstem lesions involving the vestibular nucleus can result in an SVV offset toward the side of lesion. In contrast, an upper brainstem lesion involving the interstitial nucleus of Cajal or cerebellar lesions can result in an SVV offset away from the side of lesion. Thus, both central lesions and peripheral vestibular (otolithic) lesions can cause static SVV offset and ocular torsion.

In the present study, the SVV angle obtained during on-axis rotation (bilateral centrifugation) in healthy individuals was 1° (SD = 1.5°), which was consistent with previous studies measuring SVV during on-axis rotation in normal individuals (Wetzig et al, 1990). During on-axis rotation, both utricles are exposed to equal and opposite centrifugal force (equal GIF) resulting in cancellation of the stimulus to individual utricles in normal subjects (see Figure 2). That is, if each utricle were equally functional, then there would be no perception of tilt. If one otolith were hypofunctional, however, then the contralateral (good) ear would “push” the SVV toward the opposite, diseased side. Helling et al (2006) found a strong correlation between SVV during static (stationary) and constant velocity, on-axis conditions in patients complaining of vestibular symptoms; however, 18% of patients with normal static SVV had abnormal SVV during rotation. These findings suggest that SVV during rotation may be a more sensitive measure of vestibular involvement than static SVV.

In normal individuals, the SVV tilts symmetrically during unilateral centrifugation. That is, when the subject is positioned to the right side of the axis of rotation, the SVV is tilted toward the left; and when the subject is positioned to the left side of the axis of rotation, the SVV is tilted in a similar magnitude to the right. Wetzig et al (1990) demonstrated that the magnitude of the SVV was affected by the eccentricity of the rotary chair. Specifically, minimal SVV angles are obtained when the axis of the chair rotation is closer to the midline of the head, and larger SVV angles are obtained when the chair is positioned further from the midline of the head. In the present study, the chair was offset 3.5 cm in each direction, and the mean SVV angle was 5° during left centrifugation and -3° during right centrifugation.

It is interesting to note that the greatest variability in the SVV angles occurred in the unilateral centrifugation conditions with SVV angles ranging from 0 to 11°. Figure 6 shows individual and mean SVV data for two healthy participants at each of the four test conditions. For Subject 22 (left panel), static and on-axis SVV was 0°, and the mean off-axis SVVs were -5° and 4° for the right and left, respectively. The pattern of SVV angles for this subject was similar to the majority of the subjects and consistent with previously published data for SVV during unilateral centrifugation (e.g., Wetzig et al, 1990; Böhmer and Mast, 1999; Clarke et al, 2001). In contrast, Subject 15 had SVV angles >2° for the static and on-axis conditions, and 0° SVV during the off-axis right condition (right panel, Figure 6). This pattern of findings was observed in five participants and could be misinterpreted, in the case of Subject 15, as no response to unilateral centrifugation during the offset right condition. A comparison of the off-axis SVV angles to the mean on-axis SVV angles, however, revealed a shift away from the stimulated side in all five of these participants. The reason for this pattern of response (and variability in the SVV angles) during unilateral centrifugation is unclear; however, the use of difference angles (on-axis – off-axis) removed the baseline bias and decreased the variability of the SVV angles for the off-axis conditions. Possible causes of the SVV bias may be related to the baseline (static or on-axis) head position, as it is well established that tilting the head to one side causes the SVV to deviate to the opposite side (e.g., Gloster, 1953; Böhmer et al, 1996; Wetzig et al, 1990).

In the present and previous studies, multiple trials (SVV angles) were obtained for each condition at each session. Figure 6 shows individual SVV angles (five trials) from two subjects obtained in a single test session (clockwise rotation) for each of the four test conditions. For Subject 22, the static and on-axis intratest SVV angles did not vary; however, the off-axis SVV angles ranged up to 2°. Greater intratest variability was observed for Subject 15 as the off-set left SVV angles.
ranged up to 4°. These findings were similar across participants with SVV angles ranging from 0 to 4° for all test conditions and test sessions. It is recommended, therefore, that multiple trials be obtained for clinical application of the SVV test.

The direction of chair rotation did not affect the SVV angle during unilateral centrifugation as similar SVV angles were obtained during clockwise and counterclockwise chair rotation. Since there was no effect of the direction of chair rotation on the SVV angle, test-retest reliability was only measured for clockwise rotation. The results of the present study suggest good test-retest reliability for SVV during static and dynamic conditions. To our knowledge, no previous study has examined the test reliability of the SVV during unilateral centrifugation. In the static condition, however, these results are consistent with the findings of previous studies showing good test-retest reliability for static SVV (e.g., Gómez García and Jáuregui-Renaud, 2003).

A potential obstacle to the utilization of unilateral and bilateral centrifugation as a clinical test is the requirement that the patient be strapped in a chair located in a lightproof booth and rotated at a relatively high velocity (300 deg/sec). In addition, the patient's head must be immobilized to ensure that the head moves with the chair. To determine comfort and anxiety levels related to testing, the participants were asked to complete a questionnaire following participation in the study. The results revealed that the test was relatively comfortable and did not cause anxiety in healthy young adults.

A possible limitation of this study is related to the subject sample and includes unbalanced gender (24 females and 2 males) and a limited age range (24 yr ± 2 yr). To our knowledge, however, there is little evidence of a gender effect on vestibular function. Kobayashi et al (2002) demonstrated no age effect on the static SVV, and, to date, there are no published data for age effects on SVV during on- or off-axis rotation. Although histological studies have demonstrated a linear decrease in the number of vestibular sensory cells from birth to 100 yr of age (e.g., Merchant et al, 2000), functional age-related changes have been shown to occur in the fifth to sixth decade of life for VOR (e.g., Paige, 1992) and otolith responses (e.g., Welgampola and Colebatch, 2001; Tian et al, 2002; Su et al, 2004; Chang et al, 2010). Further studies are necessary to determine the characteristics of the SVV during on- and off-axis rotation in older individuals.

CONCLUSION

In young healthy individuals, the SVV was <2° for static and on-axis rotation, and shifted up to 11° during unilateral centrifugation. We recommend the use of difference angles (on-axis SVV – off-axis SVV) to remove baseline bias and decrease the variability of the SVV angles for the off-axis conditions. Test-retest reliability of the SVV was good for all test conditions. The normative data obtained in this study may be useful in identifying patients with chronic utricular dysfunction.

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