Development of a Subjective Visual Vertical Test System Using an iPhone with Virtual Reality Goggles for Screening of Otolithic Dysfunction: Observational Study

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Abstract

Background: The subjective visual vertical (SVV) test can evaluate otolith function and spatial awareness; however, it is not widely used because of the requirement of special equipment and space, although it is performed in specialized vertigo centers using special equipment. SVV test smartphone application was developed to easily performed in outpatient facilities.

Objective: This study aimed to verify whether the subjective visual vertical (SVV) test smartphone application with commercially available virtual reality (VR) goggles can be used in a clinical setting.

Methods: The reference range was calculated for 15 healthy participants. We included 14 adult patients with unilateral vestibular neuritis, sudden sensorineural hearing loss (SSHL) with vertigo, and Meniere's disease and investigated the correlation between the SVV test results and vestibular evoked myogenic potential (VEMP) results.

Results: The SVV range of healthy participants for the sitting front-facing position was small, ranging from -2.6 to 2.3. Among the 14 patients, six (42.9%) exceeded the reference range for healthy participants. The SVV of patients with vestibular neuritis and SSHL tended to deviate to the affected side. Eleven (78.6%) had abnormal VEMP values, nine (64.3%) had abnormal cVEMP values, and six (42.9%) had abnormal oVEMP values. No significant difference was found between the SVV and cVEMP and oVEMP values ($p = 1.00$ and $p = 0.464$, respectively).

Conclusions: The SVV application can be used anywhere and in a short period while reducing directional bias by using VR goggles, thus making it highly versatile and useful as a practical otolith dysfunction screening tool.

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Abstract

Background: The subjective visual vertical (SVV) test can evaluate otolith function and spatial awareness and is performed in dedicated vertigo centers using specialized equipment;

however, it is not otherwise widely used because of the specific equipment and space requirements. An SVV test smartphone application was developed to easily perform assessments in outpatient facilities.
Objectives: This study aimed to verify whether the subjective visual vertical (SVV) test smartphone application with commercially available virtual reality (VR) goggles can be used in a clinical setting.
Methods: The reference range was calculated for 15 healthy participants. We included 14 adult patients with unilateral vestibular neuritis, sudden sensorineural hearing loss (SSHL) with vertigo, and Meniere's disease and investigated the correlation between the SVV test results and vestibular evoked myogenic potential (VEMP) results.
Results: The SVV reference range of healthy participants for the sitting front-facing position was small, ranging from -2.6 to 2.3. Among the 14 patients, six (43%) exceeded the reference range for healthy participants. The SVV of patients with vestibular neuritis and SSHL tended to deviate to the affected side. Nine (64%) had abnormal cervical VEMP (cVEMP) values, and six (43%) had abnormal ocular VEMP (oVEMP) values. No significant difference was found between the presence or absence of abnormal SVV values and the presence or absence of abnormal cVEMP and oVEMP values, however, the odds ratios suggested a higher likelihood of abnormal SVV values among those with abnormal cVEMP and oVEMP responses (P =1.0, OR=2.40 and P =.46, OR=2.00, respectively).
Conclusion: The SVV application can be used anywhere and in a short period while reducing directional bias by using VR goggles, thus making it highly versatile and useful as a practical otolith dysfunction screening tool.

Keywords: vestibular function tests; telemedicine; smartphone; virtual reality; otolith dysfunction screening tool; VEMP; iPhone

Introduction

Background

The subjective visual vertical (SVV) test measures a person's perception of verticality and is performed by placing a fluorescent bar in front of the eyes in a darkened room. It can evaluate otolith function and spatial awareness; however, it is not widely used in outpatient settings because of the equipment and space requirements. SVV tests are generally performed in dedicated vertigo centers using specialized equipment. Vestibular-evoked myogenic potential (VEMP) is commonly used for otolith dysfunction testing, but because VEMP amplitude is related to the degree of the sternocleidomastoid muscle (SCM) tone, it may be impossible to perform the test in patients who are unable to assume a cervical flexion position.

In this study

In recent years, the use of tests and diagnostic tools with smartphone applications has advanced in clinical practice. According to a review conducted in 2017, the most common otolaryngology–head and neck surgery applications used by patients were intended for hearing, tinnitus treatment, and sound measurement [1]. Recently, several SVV tests performed using smartphone applications and virtual reality (VR) goggles have been developed [2, 3, 4]. The SVV test using conventional applications is very useful for screening purposes; however, directional bias occurs when the test is conducted in a bright place, and it is difficult to make accurate assessments when the body position changes. In the current study, we aimed to develop a smartphone application dedicated to SVV evaluation and verify whether the SVV test can be easily performed in outpatient facilities by using commercially available VR goggles.

In addition, we hypothesized that if c /oVEMP and SVV are performed in patients with vestibular disorders, some relationship may be observed between c /oVEMP values and SVV values. This study may contribute to the development of new diagnostic tools for dizziness.

Methods

Overview

We developed an application called Subjective Visual Vertical, which can be downloaded for free from the Apple Store, for Education and Research. This application uses accelerometer values from the iPhone's motion manager to calculate the angle, measure the absolute vertical position, tilt angle, and SVV, and automatically calculate their average and standard deviation values. This application supports both two-dimensional (2D) and VR functions (Figure 1a, b). For the VR goggles, we used a commercially available product (Dasimon, Hu Nan, China) that is compatible with smartphones, and the focal length and the widths of the left and right eyes can be adjusted. In addition, a remote control with Bluetooth connection was used to operate the application (ELECOM VR controller, ELECOM Co. Ltd., Osaka, Japan).

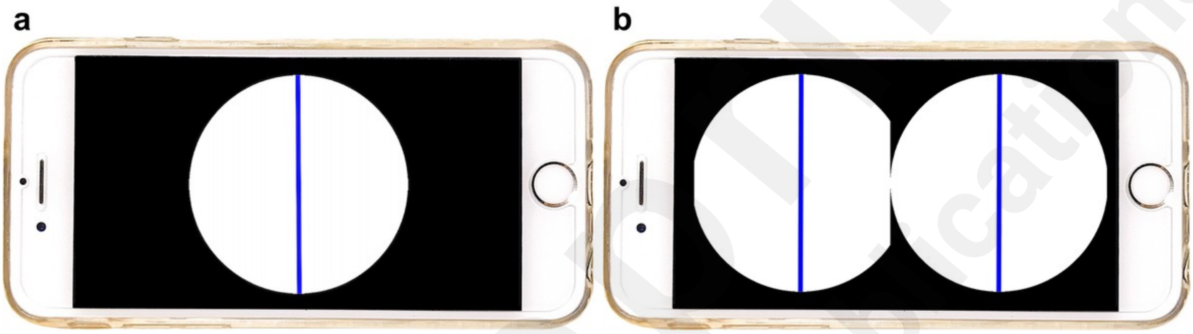

Figure 1. Application screens for 2D and VR.
a: 2D screen. b: VR screen.

An iPhone 8 (Apple, Cupertino, CA) was used for this purpose. When the application started (it can be used without an internet connection), the straight bar tilted left and right. When the user thought that the bar was vertical, the remote control was pressed to make the bar still. The mean and standard deviation values of SVV were automatically calculated and recorded in the application. The position of the SVV bar was evaluated as positive when the bar stopped in the clockwise direction relative to the absolute vertical position and as negative when it stopped in the counterclockwise direction.

The actual measurement method was performed as follows. ① Before the participants wore goggles, the operation of the application and the intention of the test were explained.② The smartphone was connected to the VR goggles worn by the examinee while the application was running (Figure 2).③ The examinee performed a practice test.④ The actual test was performed in sitting positions. The time required was approximately 5–10 min per participant (including the explanation).

Figure 2. Wearing the VR goggles and operation of the remote control.

Participants

This method was first used with 15 healthy participants (five males and 10 females; median age, 32 years). The detected SVV values were used to calculate the normal range. None of the healthy participants had a history of peripheral or central vestibular disorders. Then, 14 adult patients with unilateral vestibular neuritis (one male, two females; median age, 68 years), Meniere's disease (four males, three females; median age, 58 years), or sudden sensorineural hearing loss (SSHL) with vertigo (four females; median age, 63 years) were tested to determine the SVV values. The SVV values were measured and compared with the results of the vestibular function tests, including VEMP as well as Dizziness Handicap Inventory (DHI) scores.
For VEMP, the side with a decreased response was noted in the table.
The exclusion criteria were as follows: (1) age <20 years, (2) inability to maintain a sitting or lying position, (3) central vertigo (stroke and neoplastic lesions), and (4) traumatic unilateral vestibular disorders.

Statistical Analyses

G*Power was used to calculate the sample size [5]. The effect size was set at p = 0.5, the alpha error was 0.05, and the power was 0.8. The required sample size was calculated to be 26; therefore, a sample size of at least 13 participants per group was required.
All statistical analyses were performed using SPSS version 28 (IBM, Armonk, NY). A *P* value < 0.05 was considered statistically significant.
The quantitative continuous variables present in the study were subjected to normality tests like Kolmogrov-Smirnov and Shapiro-Wilk's tests. The results of normality tests are illustrated in Multimedia Appendix 1. The variables, 'age', 'DHI' were found to be in normal distribution

and ‘cVEMP’, ’oVEMP’, and ‘SVV value’ were found to be in non-normal distribution. Parametric tests were applied for normally distributed data and non-parametric tests were applied for non-normally distributed data. The correlation between SVV and the age of healthy participants was done using Spearman's correlation test. The association between SVV and the sex of healthy participants was explored using Mann-Whitney U test. The association between SVV values and cVEMP as well as oVEMP were done using Fisher’s exact test.

Ethical considerations

This study was approved by the clinical research ethics review committee of Dokkyo Medical University Saitama Medical Center (Approval No. : 21020), and was performed in line with the principles of the Declaration of Helsinki.
The physician conducting the study explained the research and obtained consent form all participants and obtained their consent.
Each participant was assigned a unique anonymous identifier to protect their privacy.

Results

Healthy Participant Data

Table 1 presents SVV data for healthy participants across various head positions. The mean SVV value was 0.21 with a 95% confidence interval (CI) ranging from -0.82 to 1.25. The standard error was calculated to be 0.48, indicating the precision of the mean estimate. The median SVV value was 0.71, suggesting a central tendency slightly higher than the mean. The minimum SVV recorded was -2.87, while the maximum SVV was 3.23. The reference range was calculated and included approximately 95% of the data for healthy participants, including the median value (-2.6 to 2.3). The range of SVV values spans 6.10 units, indicating considerable variability in participants' perceptions of verticality.

Table 1: SVV data among healthy participants. (N=15) : age, sex, and SVV value.

Characteristics	participants (N=15), n(%)	Values
Age(years), n(%)		
20-29	5(33)	
30-39	6(40)	
40-49	4(27)	
Sex, n(%)		
Male	5(33)	
Female	10(67)	
SVV		
Mean (95% CI)		0.21 (-0.82 – 1.25)
Standard error		0.48
Reference range		-2.6 - 2.3
Median		0.71
Minimum- Maximum		-2.87 – 3.23
Range		6.10

Table 2 displays the correlation between SVV and the age of healthy participants. The Spearman's correlation coefficient (ρ) between SVV and age was -0.045, indicating a very weak negative correlation between these variables. The associated p-value was 0.873, suggesting that this correlation is not statistically significant.

Table 2: Correlation between SVV and age of healthy participants. (N=15)

Variable	SVV	
Age	ρ	*P* value
	-0.045	.87

Table 3 presents the association between SVV and the sex of healthy participants. For male participants, the mean SVV was 0.38 with a standard deviation (SD) of 1.20, while the median SVV was 0.69 with an interquartile range (IQR) of -0.81 to 1.40. The U statistic, a measure of the difference between two groups, was 23.00. The p-value for this comparison was .86 (95% CI 0.855 – 0.869), indicating no statistically significant difference in SVV between male and female participants. For female participants, the mean SVV was 0.13 (SD 2.17), and the median SVV was 0.78 (IQR -1.95 – 1.65).

Table 3: Association between SVV and sex of healthy participants. (N=15)

Variable	Mean (SD)	Median (IQR)	U	*P* value (95% CI)
Sex				
Male	0.38 (1.20)	0.69 (-0.81 – 1.40)	23.00	.86 (0.855 – 0.869)
Female	0.13 (2.17)	0.78 (-1.95 – 1.65)		

Patient Data

All patient data are shown in Table 4. Among those diagnosed with vestibular neuritis, patients' ages ranged from 40 to 72 years, with both genders represented. SVV values varied from -5.00 to 0.20, with spontaneous nystagmus observed in all cases. Regarding sudden sensorineural hearing loss, patients were predominantly female and aged between 46 and 76 years, with SVV values ranging from -0.24 to 16.76. Meniere's disease patients, primarily female and aged between 47 and 84 years, exhibited SVV values ranging from -5.30 to 5.03. Diagnostic tests such as cervical and ocular vestibular evoked myogenic potentials (cVEMP and oVEMP) were administered, with variable results across patients. Additionally, DHI scores ranged from 2 to 88, indicating varying degrees of functional impairment due to dizziness. Outliers are identified in the table using bold type, indicating the data points that deviated significantly from the norm within the dataset.

Table 4: List of all patient data (N=14): disease, age, affected side, sex, SVV value, spontaneous nystagmus, cVEMP, oVEMP, and DHI score.

Disease	Side	Sex	SVV value	Spontaneous nystagmus	c VEMP	o VEMP	DHI score
Vestibular neuritis							
Age(years)							
40	R[a]	F[c]	0.20	+	N[f]	R	76
68	L[b]	F	**-5.00**[e]	+	N	L	28
72	L	M[d]	**-2.52**	+	N/A[g]	N/A	2
Sudden sensorineural hearing loss							
46	R	F	2.29	-	N	N/A	64
61	R	F	**9.39**	-	R	R	N/A
76	R	F	-0.24	-	B[h]	B	10
65	R	F	**16.76**	+	R	R	74
Meniere's disease							
57	R	F	0.19	-	R	N/A	14
47	R	F	1.39	-	R	B	4
84	R	F	**-5.30**	-	B	N/A	40
58	L	M	-0.29	-	N	N/A	88
64	L	M	-1.40	-	L	R	38
79	L	M	**5.03**	-	L	N/A	12
66	L	M	2.19	-	R	N	26

[a]R: right
[b]L: left
[c]F: female
[d]M: male
[e]:Bold type indicates an outlier.
[f]N: normal

[g]N/A: not applicable
[h]B: bilateral

Subjective Visual Vertical

Table 5 presents the association between SVV values and cVEMP and oVEMP results. Among the 14 patients, six (43%) had abnormal SVV values. Among the 14 patients, nine (64%) had abnormal cVEMP values, six (43%) had abnormal oVEMP values, and 12 (86%) had abnormal SVV or VEMP values.
When examining cVEMP, among those with normal cVEMP responses, three (38%) had normal SVV values, while five (63%) had abnormal SVV values. Among those with abnormal cVEMP responses, four (80%) had abnormal SVV values. The p-value for this association was 1.0, indicating no statistically significant relationship between cVEMP and SVV values. However, the odds ratio (OR) was 2.40 (95% CI: 0.18 – 32.88), suggesting a higher likelihood of abnormal SVV values among those with abnormal cVEMP responses, although this was not statistically significant. Similarly, when analyzing oVEMP, among those with normal oVEMP responses, two participants (40%) had normal SVV values, while three (60%) had abnormal SVV values. Among those with abnormal oVEMP responses, all patients (100%) had abnormal SVV values. The p-value for this association was .46, indicating no statistically significant relationship between oVEMP and SVV values. The OR was 2.00 (95% CI: 0.90 – 4.45), suggesting a trend towards abnormal SVV values among those with abnormal oVEMP responses, though it was not statistically significant.
Four had abnormal SVV and cVEMP values, two of whom showed deviation to the affected side of the SVV and the abnormal side of the cVEMP. Three had abnormal SVV and oVEMP values, all of whom showed deviation to the affected side of the SVV and the abnormal side of the oVEMP.

Table 5: Association between SVV with cVEMP and oVEMP. (N=14)

Variable		SVV value		*P*	OR (95% CI)
		Normal n (%)	Abnormal n (%)		
cVEMP	Normal	3 (38)	1 (20)	1.0	2.40 (0.18 – 32.88)
	Abnormal	5 (63)	4 (80)		
oVEMP	Normal	2 (40)	0 (0)	.46	2.00 (0.90 – 4.45)
	Abnormal	3 (60)	3 (100.0)		

Correlation of SVV with Age, Sex, Affected Side, and DHI Score

Table 6 displays the correlation between SVV values and both the age and DHI scores of patients. The Spearman's correlation coefficient (ρ) between SVV and age was -0.327, suggesting a moderate negative correlation, although the p-value of .25 indicates that this correlation is not statistically significant. Similarly, the correlation between SVV and DHI scores yielded a Spearman's correlation coefficient of 0.077, indicating a moderate positive correlation, but again, the p-value of .80 indicates that this correlation was not statistically significant.

Table 6: Correlation between SVV with age and DHI score of patients. (N=14)

Variable	SVV	
	ρ	*P* value
Age	-0.327	.25
DHI score	0.077	.80

Table 7 presents the association between SVV values and both the sex and affected side of patients. Among male patients, the mean SVV value was 0.60 (SD = 3.02), while the median SVV was -0.29 (IQR -1.96 –3.61). For female patients, the mean SVV value was higher at 2.19, with a larger SD of 6.95, and a median SVV of 0.20 (IQR -2.62 – 5.84). The U statistic, measuring the difference between male and female SVV values, was 19.00 (*P* = .70, 95% CI 0.692– 0.710), indicating no statistically significant difference in SVV between male and female patients. Regarding the affected side of the patients, those with right-sided conditions exhibited a higher mean SVV value of 3.09, compared to -0.33 for left-sided conditions. The median SVV for right-sided conditions was 0.80 (IQR -0.13 – 7.62), while for left-sided conditions, the median SVV was -0.85 (IQR -3.14 – 2.90). The U statistic comparing right and left-sided SVV values was 15.00, (*P* = .28, 95% CI 0.271 – 0.288), indicating no statistically significant difference in SVV between patients with right and left-sided conditions.

Table 7: Association between SVV with sex and side of patients. (N=14)

Variable	Mean (SD)	Median (IQR)	U	*P* value (95% CI)
Sex				
Male	0.60(3.02)	-0.29 (-1.96– 3.61)	19.00	.70 (0.692 – 0.710)
Female	2.19 (6.95)	0.20 (-2.62 – 5.84)		
Affected side				
Right	3.09(6.85)	0.80 (-0.13 – 7.62)	15.00	.28 (0.271 – 0.288)
Left	-0.33(3.54)	-0.85(-3.14 – 2.90)		

Discussion

Principal Results

The reference range was calculated for 15 healthy participants, including the median value. The mean values and reference ranges were 0.21 (reference range, -2.6 to 2.3) for the sitting position. There was no significant correlation between the SVV values and age or sex in the healthy participants. Among the 14 patients with unilateral peripheral vestibular disorder six (43%) had abnormal SVV values. Among the 14 patients, nine (64%) had abnormal cVEMP values, six (43%) had abnormal oVEMP values, and 12 (86%) had abnormal SVV or VEMP values. No significant difference was found between the presence or absence of abnormal SVV values and the presence or absence of abnormal cVEMP and oVEMP values, however, the ORs suggested a higher likelihood of abnormal SVV values among those with abnormal cVEMP and oVEMP responses (*P* =1.0, OR=2.40 and *P* =.46, OR=2.00, respectively).

Comparison with Prior Work

Regarding the SVV reference range, the absolute value of SVV was previously reported to be 2–3° for static SVV [6, 7]; the results of this study are similar with the findings of previous studies. In the present study, there was no correlation between age and SVV values, thus indicating that the SVV test was not affected by age and was a stable test with slight variability; Zwergal et al. [7] also reported this finding. In contrast, Toupet et al. [8] reported that SVV values were smallest in patients aged 20–49 years and greater in patients aged 0–19 years and ≥80 years.

In the present study, six (43%) of 14 patients with unilateral peripheral vestibular disorder had abnormal SVV. The abnormality detection rate of SVV was comparable to that of oVEMP and lower than that of cVEMP. Although VEMP and SVV are tests that assess the otolithic system, they assess vestibulospinal reflexes and spatial cognition, respectively, and the detection rates vary depending on the pathology and stage of the disease. In this study, twelve patients (12/14, 86%) had abnormal SVV or VEMP, and suggesting a higher likelihood of abnormal SVV values among those with abnormal c/oVEMP responses, although this was not statistically significant. SVV, in combination with VEMP, may be used as a screening test for otolithic dysfunction.

Limitations

This study had some limitations. First, although the sample size was set using G*Power, a multivariable analysis could not be performed because of the small number of cases. Second, the relationship between the abnormal SVV rate and VEMP by disease was unclear. Some previous studies have reported no correlation between SVV and oVEMP [9], while others have reported a significant correlation between SVH and oVEMP test results [10]. Future analysis should be limited to the stage and disease. The advantages of the SVV test using a smartphone application and VR goggles are that the test is inexpensive, quick, and can be performed in an outpatient setting without the need for special equipment.

Conclusion

In conclusion, our SVV application is currently available for the iPhone and can be used without an internet connection after being downloaded; therefore, it can be used anywhere. The average time required for the test in this study was 5 min, thus making it easy to perform during outpatient consultations. Therefore, SVV applications have the potential to make a significant contribution as a screening test for otolith dysfunction in telemedicine. Furthermore, a noteworthy advantage of the newly developed application is that it supports VR and 2D. Thus, by using VR goggles, it is possible to reduce the directional bias caused by inspections when conducting the test in a dark place and against a circular background, similar to that in the bucket test [7].

Acknowledgments

None.

Data Availability

The datasets generated and analyzed during the present study are available from the corresponding author upon reasonable request.

Generative Artificial Intelligence

No generative artificial intelligence was used in the preparation of any portion of this manuscript.

Conflict of interest

None.

Abbreviations

JMIR: Journal of Medical Internet Research
RCT: randomized controlled trial
SVV: subjective visual vertical
VEMP: Vestibular-evoked myogenic potential
SCM: sternocleidomastoid muscle
VR: virtual reality
SSHL: sudden sensorineural hearing loss
DHI: Dizziness Handicap Inventory

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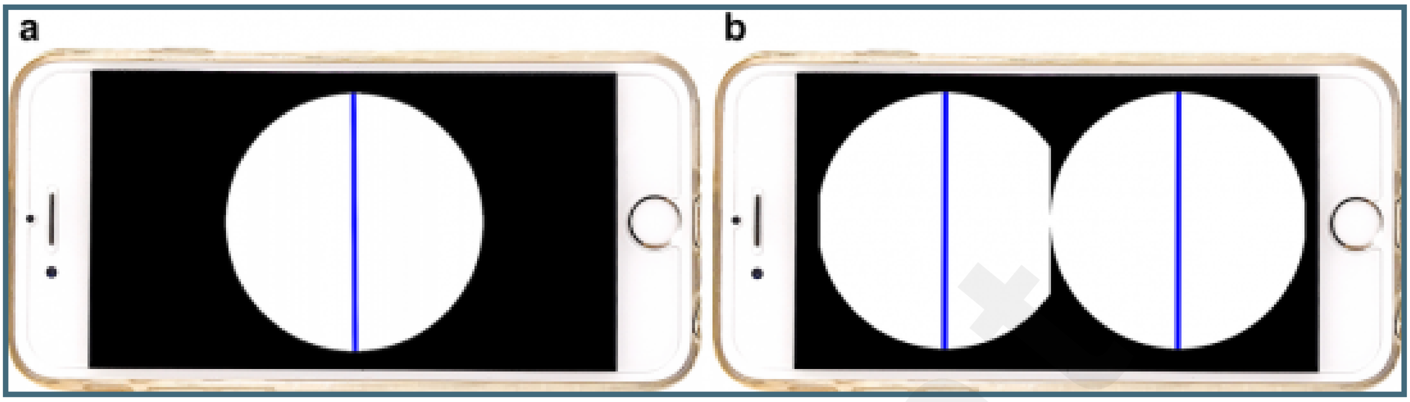
Supplementary Files

Figures

Application screens for 2D and VR. a: 2D screen. b: VR screen.



Wearing the VR goggles and operation of the remote control.

Multimedia Appendixes

Normality test results for the study variables.
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