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PAPER

Assessing Subjective Visual Vertical Reliability: A Comparison of the "Bucket Test," a Mobile App, and a Virtual System

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ABSTRACT

The subjective visual vertical (SVV) is a potential indicator of vestibular dysfunction as it assesses an individual's perception of a vertical line. Despite this, and as a result of specific logistical impediments, SVV has not entered standard clinical practice. Dizziness is the third most common clinical complaint by patients (20%) in outpatient offices. It adversely affects the patient's life and is often accompanied by intensive healthcare. This study aims to determine whether the bucket test and mobile phone app are as reliable as the Virtual SVV system in assessing the SVV. This study involves four types of investigation to determine the relationship or difference among three tests, including their performance comparison, descriptive analysis, one-way ANOVA test, receiver operating characteristic (ROC) curve, and correlation analysis. After organizing the raw data from 207 healthy volunteer participants for 8 trials, it was found that 59% were female and 41% were male. The data was analyzed utilizing the SPSS program. The test performance is measured using the ROC curve, and the results indicate that the bucket with the highest ROC coefficient is 0.72.

KEYWORDS

subjective visual vertical (SVV), dizziness, SPSS, bucket test

1 INTRODUCTION

Balance, defined as the ability to maintain the body's center of gravity over its base of support (BOS) [1], is a fundamental aspect of functional living. It depends on three systems that work together to maintain our balance. These include the visual, somatosensory, and vestibular systems [2]. The vestibular system is essential for maintaining gaze and postural stability. Additionally, please provide us with information regarding the position of our body in space [3]. However, dysfunction of the vestibular system can cause various symptoms, such as oscillopsia, gait abnormalities, postural instability, dizziness, nausea, and vomiting [4].

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Dizziness is a broad term that people use to describe their symptoms. The most common symptoms associated with dizziness are vertigo, nonspecific dizziness, disequilibrium, and presyncope. Thus, to evaluate the patient, it is important to fit the patient with typical symptoms into one of these categories [5]. For example, vertigo is important to fit vestibular disorders, and presyncope is typically caused by cardiovascular diseases. Dizziness affects our balance, leading to falls and gait disturbance. It originates from vestibular disorders such as benign paroxysmal positional vertigo, neuritis, labyrinthitis, and Meniere's disease, as well as non-vestibular disorders, cardiovascular issues, and psychogenic disorders.

Dizziness is the third most common clinical complaint among patients (20%) in the outpatient department [6]. It has a negative impact on the patient's life, and it is often accompanied by a significant healthcare burden [7]. Although dizziness is not life-threatening, it can lead to various complications such as falls, functional disability, anxiety [8], gait disturbance, and a negative impact on social life [6]. Dizziness is a vague symptom that might include a spinning sensation (vertigo), disequilibrium, presyncope, lightheadedness, or a nonspecific type of dizziness.

Dizziness can affect individuals of all ages, although it is rare in children. The prevalence of dizziness is approximately 30% for older adults over 65 years old [9], while in young people, it is 23.2% [10]. The prevalence of dizziness in the US is 14.8%, which means 33 million people [11]. One study measuring the prevalence of vestibular disturbance has reported that more than one-third of people aged 40 or older in the US, which means up to 69 million citizens, have experienced some form of vestibular disturbance [12].

One of the factors that affect balance and cause dizziness is the alteration of the subjective visual vertical (SVV), which refers to the individual's inability to perceive verticality without any visual cues [13]. The ability to perceive verticality would be affected if there was dysfunction in the otolith (an organ in the inner ear), leading to dizziness in the patient. Patients with vestibular disorders may have difficulty identifying the vertical line, leading to a veering from upright posture, which is measured in degrees. This can result in an imbalance for patients [14]. The SVV can be tested in a static manner, where the head is in the midrange, and in a dynamic manner, where the head is rotated a few degrees, e.g., 45 degrees to the right or left [15]. Many central and peripheral vestibular disorders have exhibited abnormalities in the SVV. Moreover, the SVV can be abnormal in some patients with benign paroxysmal positional vertigo (BPPV), where vertigo is the primary complaint. Patients with BPPV typically tilt toward the affected side, but there is a significant improvement in SVV after treatment [16]. Furthermore, most patients with vestibular neuritis exhibit abnormal SVV. The recovery after vestibular neuritis, which improves the results of tests used to assess otolith function, is faster than the examination related to the canal, such as in the case of BPPV [17].

There are various techniques and tests in vestibular rehabilitation used to assess SVV abnormalities and provide optimal vestibular rehabilitation interventions. The SVV can be assessed by:

1. **Bucket test:** This is a simple and cost-effective method to perform and is thought to have comparable results to other more expensive methods for discriminating asymmetric articular function. The original test description involves using a bucket with a plumb line on the outside to allow the examiner to assess the degree of tilt [18].
2. **Mobile Phone App:** A study validated a method that measures the deviation from the SVV using a mobile application installed on a smartphone fixed to a turntable anchored to the wall. The study found that the standard deviations of the iterations from each subject in the app method are statistically smaller than those of the plumb line, indicating that the app is a more precise test [18–19].

3. **Virtual SVV system:** Although there is no specific example of a virtual SVV system in the search results, it is worth noting that technological advances have made many tests accessible and feasible in the clinical environment. The SVV is one such test that assesses a person’s ability to perceive the gravitational vertical [20].

Subjective visual vertical is a sensitive test for vestibular dysfunction and a measure of the perceived verticality of subjects. Despite this, SVV has not yet entered the mainstream of medical practice due to technological and logistical challenges. SVV is typically assessed in a “static” setting, in which subjects are asked to align a line or rod to the vertical of the Earth against a black stationary background with no reference frames. Recent research has shown that the dynamic SVV test, in which the rod or line is displayed against a changing backdrop, has significant benefits. This study aimed to determine whether the bucket test and mobile phone app are as reliable as the virtual SVV system in evaluating SVV abnormalities. Analyzing the performance of the virtual SVV test, bucket test, and mobile phone app individually. Developing a method that is robust and accurate in comparing the three tests.

2 LITERATURE REVIEW

Numerous studies have examined the concept of subjective visual vertical and its assessment methods. In Brazil, an HP Pavilion with a 15.4-inch screen was used to measure the SVV in adults with bilateral vestibular diseases and propose a new method for analyzing SVV data. [21]. The research involved 40 participants in two groups. The first group consisted of 20 healthy individuals, while the second group comprised 20 patients with bilateral vestibular dysfunction. In a dimly lit room, participants sat in height-adjustable chairs for the assessment. A computer program that highlights a line. Head tilting was prevented by using a neck collar. The SVV test was conducted six times by adjusting the position of the highlighted line to be vertical using the computer mouse. The average was calculated. Patients with bilateral vestibular impairment reported impaired perception of visual verticals compared to healthy subjects [21].

Due to its association with disequilibrium in stroke patients, some researchers have examined SVV as an evaluation tool. A 2006 study examined 30 cerebral stroke patients with motor and balance disorders [22]. It started three months ago. This study investigated the impact of balance abnormalities on stroke patients’ perception of the vertical line. To investigate whether aberrant SVV in hemiplegic patients causes balance issues. SVV and balance were assessed in all patients. The postural assessment scale for stroke (PASS) was used to assess balance, and the SVV was measured in a dark room with patients seated on a chair. Hemineglect and postural instability were observed in 40% of patients undergoing SVV tilting. Poor balance was associated with abnormal SVV findings [22].

The assessment of SVV was conducted in a study involving ten toddlers and twelve young adults [23]. The examination room was dimly lit, and a large black curtain hung from the ceiling to conceal the subjects and obscure details. The foot angles were 30°, and the heels were 4 cm apart while the subjects stood over the force plate. A do-it-yourself SVV device was created using a phosphorescent tube and clown-shaped fluorescent cardboard. This device was used to evaluate SVV from a distance of 2 meters. SVV was assessed simultaneously under four conditions: in the dark or with eyes closed, while observing moving dots, and while fixating on a vertical bar. The clown spun in random directions, and the contestant had to balance it vertically. Children demonstrated poorer postural stability compared to younger adults, as well as higher variability and less accuracy in perceiving vertical lines [23].

Curator SVV is a viable clinical approach [24]. The study attempted to validate Curator SVV by obtaining normal results and assessing its potential for use with patients. This research examined 20 patients' vestibular dysfunction using Curator SVV and VestiTest® devices. Randomly tilted images flashed on the dark screen. Patients used a wireless remote to rotate photographs horizontally. The patients had to align the lines vertically by rotating them. The SVV assessment by Curator SVV and VestiTest® was similar.

Recent research contradicts previous findings suggesting that the bucket test may accurately detect SVV in patients with vestibular dysfunction. This study involved 50 healthy participants, 25 of whom had unilateral posterior BPPV and 25 with unilateral vestibular hypofunction. This study investigated the impact of BPPV and unilateral vestibular hypofunction on the perception of SVV. The study also investigated the feasibility of clinical SVV testing. All subjects were diagnosed based on historical data and clinical examination. All patients with benign paroxysmal positional vertigo had positive outcomes on the Dix-Hallpike maneuver. Patients with BPPV and unilateral vestibular hypofunction showed no statistically significant difference between the affected and unaffected sides. Neither group consistently headed towards the affected area. The mean values of the control group, the unaffected side, the affected side, and the combined data from both sides among patients differed significantly. The user submitted the number [25].

Another study investigated the bucket test in healthy individuals. The study involved 50 healthy individuals who underwent normal ontological and neurological examinations. Any individual with abnormal ontological or neurological exams was excluded. Bucket tests were conducted to test the SVV. The subject sat upright and placed his face in the bucket. Without external visual cues, patients tried to see the vertical line at the bottom of the bucket. The bucket was randomly turned either clockwise or counterclockwise to test the SVV. This was done ten times: five times clockwise and five times counterclockwise. The bucket test is a simple, cost-effective method that enhances vestibular clinic care. The normal range for healthy individuals is –1.0 to +3.0 [26].

Only one study has utilized the SVV module (Synapsis, France), which is similar to the virtual SVV system (interacoustics) used in the comparative study. A 14-month prospective cross-sectional study utilized synapsis (France) to investigate the SVV and subjective visual horizontal in healthy individuals. Inclusion does not require any ontological or vestibular abnormalities. 82 subjects underwent neuro-ontological evaluation for the research. Both dynamic and static tests were conducted six times and recorded. These findings were positive or negative, depending on the perspective. The study considered SVV and subjective visual horizontal (SVH) in cases of acute vestibular loss. Static SVV and SVH adjust more quickly than dynamic ones. The study found no significant difference in SVV and SVH outcomes between women and men, or between individuals aged 20–40 and those aged 40–60. This data can also be used as a reference for future studies on chronic dizziness and otolith organ dysfunction [27].

A mobile virtual reality system called VIRVEST was utilized to test the SVV in research. VIRVEST is a wearable virtual reality device that provides doctors with SVV data when assessing patients. The technology includes 3D mobile software, a Samsung Gear VR headset that patients must wear, and a smartphone (the Samsung Galaxy S7) fixed to the headset. Websites will receive the results. The study involved 41 healthy participants who had normal neuro-ontological exams. Each participant received adjustments to their headset and instructions. Each participant completed four tests: static SVV, dynamic SVV with a clockwise rotated backdrop, dynamic SVV with a counterclockwise rotated background, and SVV with a virtual reality environment. The dynamic and virtual reality backgrounds increased the sensitivity of the test. Participants had to view the vertical line six times during each test. Clinicians can utilize the VIRVEST system because of its accuracy and reliability. The outcomes of static, dynamic, and virtual reality were similar [28].

3 MATERIALS AND METHODS

The primary objective of this study was to perform a comparative analysis of three different tests in order to identify the most effective method for assessing visual and vertical abnormalities. To achieve the intended objective, the first phase involves collecting data from three distinct tests: the bucket test, the SVV virtual test, and the mobile phone app test, each conducted with a diverse group of people. The next step involves organizing the data, transforming it into Excel spreadsheets, and systematically arranging it. Furthermore, the data is analyzed using the SPSS program. The data underwent analysis using descriptive statistics and the one-way analysis of variance (ANOVA) test in SPSS. The findings from the graphs and tables are compared to draw conclusions about the performance analysis of the three approaches. Figure 1 depicts a flowchart illustrating the design method used to analyze the three tests.

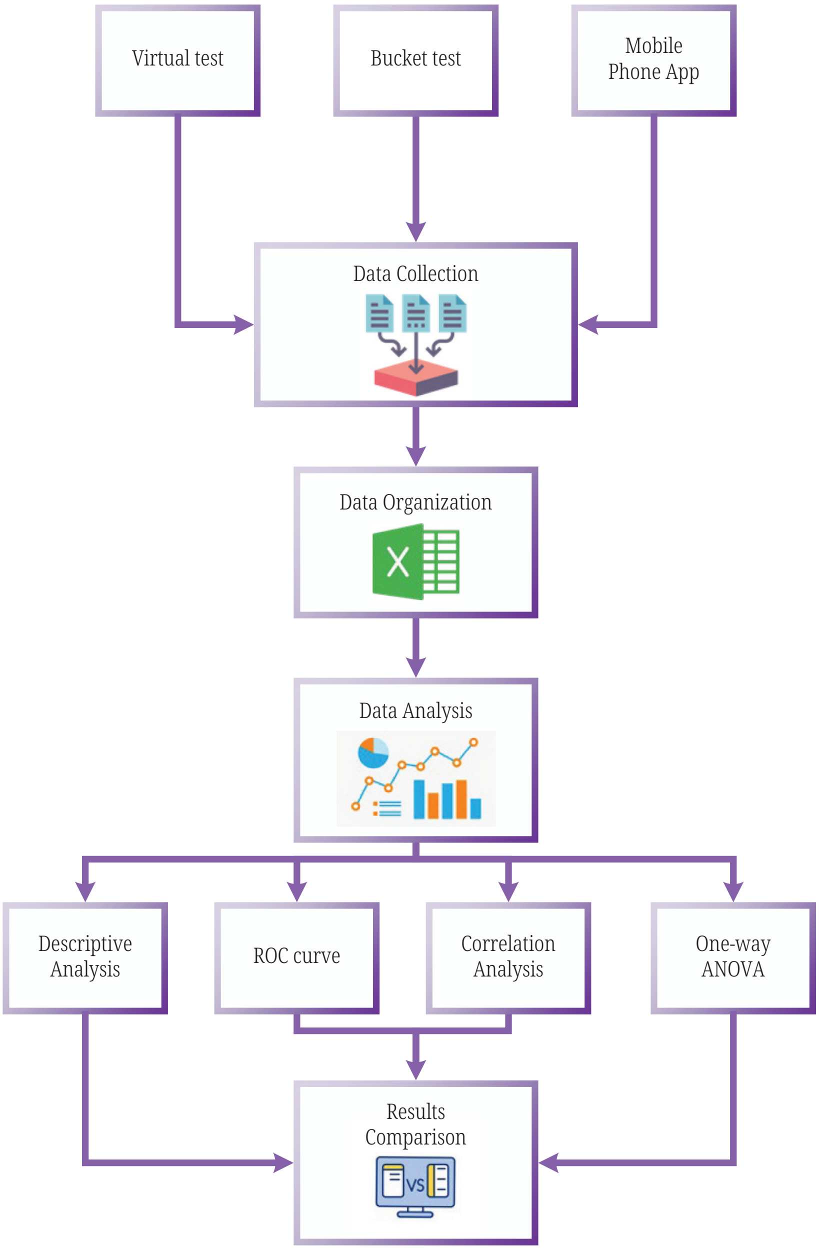


Fig. 1. Flow chart of the design process

3.1 Data collection

The study will last for two months, and each participant will be required to undergo three techniques: the bucket test, the mobile phone app, and the virtual SVV system, in order to examine the SVV. Two vestibular examination experts utilized the bucket test, a mobile phone app, and a virtual test to assess SVV testing in all individuals. The data is to be collected by two biostatisticians; one will enter the data and the other to check for and detect errors.

The bucket test involves a plastic bucket with a vertical line drawn on the inside base and a printed protractor on the outside base. Thus, the zero mark of the protractor is parallel to the vertical line. A string with a weight is fixed and hangs in the center of the base outside and above the protractor. As the bucket is rotated, the string moves across the scale to measure the angle of inclination from the vertical. Each direction is repeated five times, resulting in a total of 10 repetitions. Each time, we ask the participant to perceive the vertical line and record the reading. Deviating by more than 2 degrees is considered abnormal. Figure 2 depicts the setup of the bucket test.

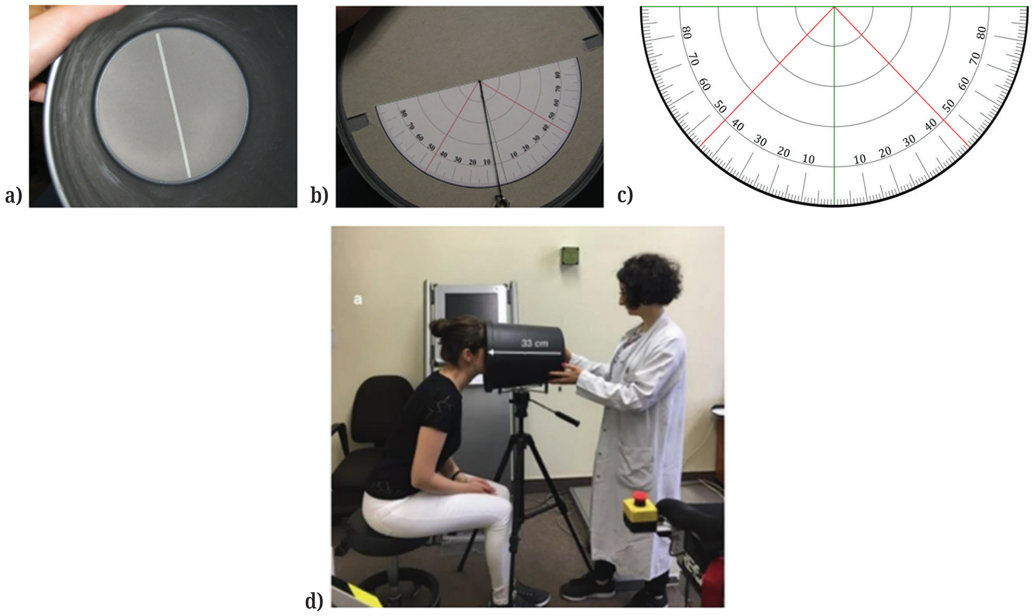


Fig. 2. Bucket setup (a) view from inside (b) view from back (c) measurement scale (d) measurement using bucket test

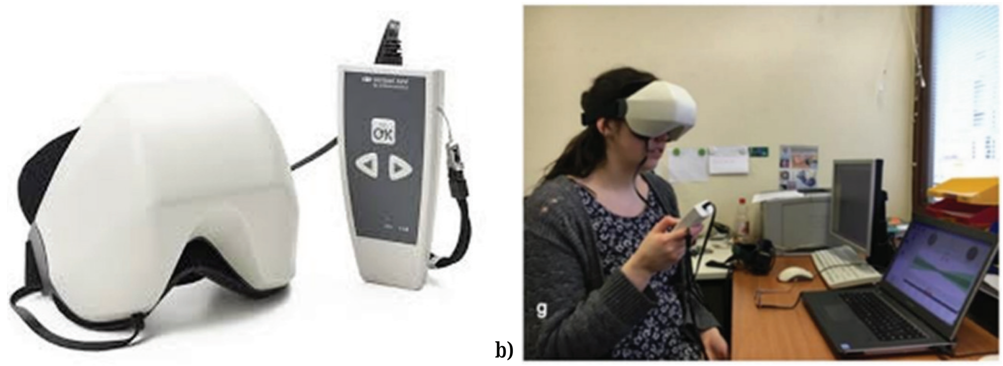
3.2 Mobile phone App test

Mobile applications have become increasingly important in the healthcare sector because they provide instant access to health-related information and services. They can facilitate communication between healthcare providers and patients, enable remote patient monitoring, and provide educational resources for both patients and professionals. Furthermore, these applications can help manage appointments, remind users to take medication, and track health metrics such as heart rate, sleep patterns, and physical activity. By improving patient engagement and promoting proactive health management, mobile apps are revolutionizing healthcare delivery and contributing to improved health outcomes [29–31].

The Visual Vertical is a mobile phone application for iOS and was the second technique. We downloaded it from the examiners’ mobile to use it with our participants. Then the mobile phone got stuck at the bottom of the bucket. The participants were clearly instructed to place their faces inside the bucket and then identify the vertical line. As in the bucket test, the bucket was randomly rotated to the right and then to the left. Each direction is repeated multiple times, totaling eight repetitions. In each trial, the participant was asked to perceive the vertical line and record the reading. A deviation of more than 2 degrees is abnormal. In this experiment, a bucket similar to the test bucket is used, but with a smartphone attached to the bottom of the bucket’s interior using the Visual Vertical App.

3.3 Virtual SVV test

The virtual SVV system involves goggles, a handheld remote used by the participant to adjust the vertical line, and SVV software that needs to be installed on a laptop. The examination was conducted in a dark room to eliminate visual cues. The participant sat on a chair with their head and neck in a neutral position. The seat height was adjusted to align the vision with the center of the screen. The line was randomly rotated to the right and left. The test was repeated eight times, and the results were recorded each time. Figure 3a depicts the components of the virtual system, while Figure 3b illustrates the setup of the virtual system.



a) b)

Fig. 3. (a) SVV virtual test setup (b) measurement using SVV virtual setup

3.4 Data organization and analysis

Using three different setups, data was collected from 207 healthy volunteer participants for 8 trials. Of the participants, 59% were female and 41% were male, and the data was recorded on the sheets. Participants were healthy adults aged 18 years or older. Participant inclusion criteria included passing a pure-tone air conduction screening test administered at 25 dB HL at the octave frequencies of 250–8000 Hz in each ear and having normal tympanometry in each ear. Similarly, the demographic data of the subjects, including age, gender, height, and weight, is also included. The data was then entered into an Excel sheet and organized for processing in SPSS software. There were eight trials for each subject and test, so before conducting the SPSS analysis, the data entered in the Excel sheet was averaged for eight trials for each test.

Statistical analysis was conducted using IBM SPSS Statistics, version 26. First, descriptive statistics and the one-way ANOVA test were used to assess the normal distribution of the variables. For the SPSS analysis, significance was defined as a p-value less than 0.05.

Descriptive analysis is used to describe the basic features of the data for the study. It provides summaries of data measures along with graphical representations of the quantitative analysis of the samples. The descriptive measures are brief coefficients that provide a summary of the given data. In this case, we have data on the test results for 207 subjects using three different techniques. This analysis includes two measures: spread and central tendency. The central tendency measures include the median, mode, and mean, while measures of variability include variance, skewness, standard deviation, minimum, maximum, and kurtosis. This analysis measures the mean, standard deviation, range, skewness, kurtosis, mode, variance, minimum and maximum values, and median [32].

Statistically significant differences among three or more independent group means are determined using a one-way ANOVA. ANOVA checks whether the means of treatments differ from the means of the dependent variable to determine if the levels of the independent variable create statistically distinct groups. The null hypothesis is rejected if any group differs significantly from the overall mean. ANOVA calculates significance using the F-test. Unlike a t-test, multiple means can be compared at once because the error is calculated for the entire set of comparisons rather than for each pairwise comparison. The mean variance of each group is compared to the variance of the entire group using the F-test. If the variance within groups is less than the variation between groups, the F-test will produce a larger F-value, indicating that the difference is statistically significant [33].

This study aims to identify whether the bucket test and mobile phone app are as reliable as the virtual SVV system in evaluating SVV abnormalities. Therefore, a one-way ANOVA test is performed in the SPSS software for this purpose. ANOVA is a statistical method used to analyze differences among groups in a study. In this study, certain assumptions were applied, including:

1. In each group of tests, a random sample is represented.
2. Each population is distributed normally.
3. The variance of each group is homogenous.

Binary response variable regression models are developed using logistic regression. The sensitivity and specificity of a logistic regression model are depicted on the ROC curve. It easily visualizes these two metrics. Highly specific and sensitive models have ROC curves in the top-left quadrant. Models with low specificity and sensitivity have a 45-degree curve that easily approximates the diagonal line. The area under the curve (AUC) measures the model's ability to distinguish between positive and negative events. The AUC ranges from 0 to 1 and is often used to measure a model's accuracy in identifying outcomes using the AUC metric. A larger AUC indicates superior performance [34].

The correlation coefficient (r) ranges from 1 (indicating a positive correlation) to –1 (indicating a negative correlation) and is utilized to determine a linear relationship between two variables. Pearson's r measures the linear relationship between two continuous variables. When variable A rises, variable B also increases; this is indicated by a positive correlation coefficient (r). In contrast, a negative correlation value indicates that variable B decreases as variable A grows. A correlation value of 0 indicates no linear relationship between variables. Remember that correlations are only applicable to linear relationships between variables. A correlation value of zero may indicate a non-linear relationship. Various associations are interpreted in a similar manner [35].

4 RESULTS

The aim of this study was to assess the reliability and variability of the test-retest of the virtual SVV system, a commercially available SVV system (interacoustics). Furthermore, the study attempted to compare the reliability of the virtual system with that of a previously existing bucket test and a mobile phone app called SVV. This study involved 207 healthy subjects, each participating in 8 trials for each test. The participants must undergo all three tests. Any results from participants with an incomplete test or who have withdrawn from the study are excluded. SPSS (statistical package for the social sciences) is used for the analysis of data. In the data analysis of the dataset, we conducted four types of analyses: descriptive analysis, one-way ANOVA analysis, ROC curve analysis, and correlation analysis. First, database information is organized into Excel sheets before being processed in the SPSS software. The data is then analyzed in SPSS, which generates graphs and tables in the output.

Table 1 presents the descriptive analysis of three tests: the bucket test, mobile phone app, and virtual SVV test, used to assess the SVV. This analysis measures the mean, standard deviation, range, skewness, kurtosis, mode, variance, minimum and maximum values, and median. From Table 1, it can be observed that the standard deviation values for the mobile app test and virtual SVV test are 1.2 and 1.8, respectively. Similarly, the variances are 1.5 and 3.5, and the ranges are 9.8 and 13.7. Therefore, some of the parameters' values for the mobile app test are closer to those of the virtual SVV test compared to the bucket test values.

Table 1. Descriptive analysis summery of three tests

		Bucket Test	Mobile Phone App	Virtual SVV Test
N	Valid	207	207	207
	Missing	0	0	0
Mean		.603	–.7250	–.065
Std. Error of Mean		.065	.085	.130
Median		.50	–.6125	–.075
Mode		.312[a]	–.612	–2.150[a]
Std. Deviation		.9450	1.237	1.873
Variance		.893	1.531	3.510
Skewness		.264	–1.011	–.122
Std. Error of Skewness		.169	.169	.169
Kurtosis		.407	4.146	1.461
Std. Error of Kurtosis		.337	.337	.337
Range		5.25	9.78	13.387
Minimum		–1.56	–7.562	–7.28

Figure 4 shows the box and whisker graph for the three different tests conducted on the subjects; the SVV test is in the middle of the other two tests.

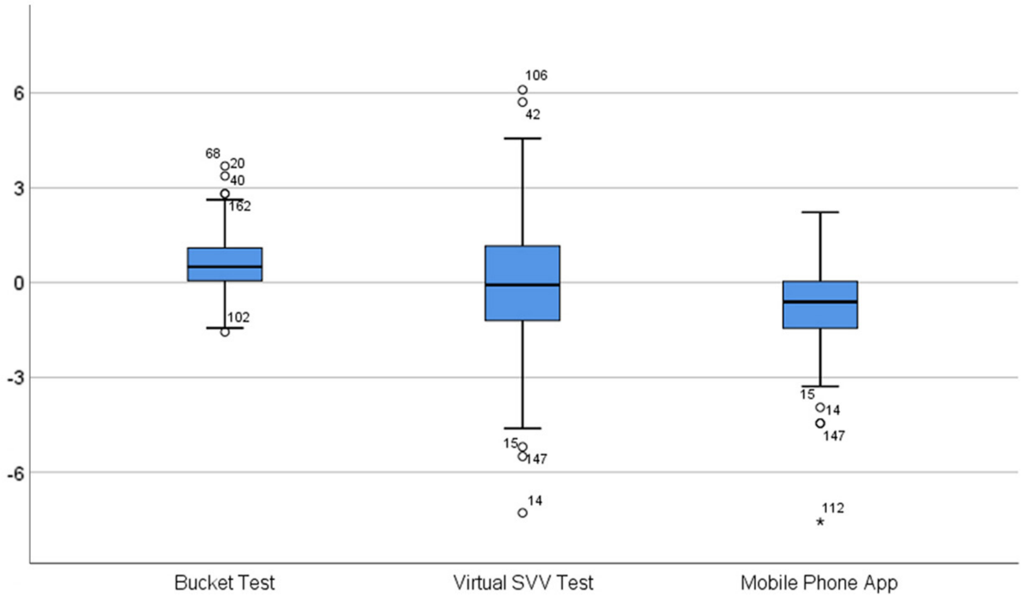


Fig. 4. Box and whisker plot for the three tests

Table 2. Descriptive analysis summery of the subjects

Statistics				
		Age	Height	Weight
N	Valid	207	207	207
	Missing	0	0	0
Mean		34.89	164.93	74.90
Median		33.00	165.00	74.00
Mode		33	165	70
Std. Deviation		8.229	9.540	15.487
Range		48	69	75
Minimum		18	123	41
Maximum		66	192	116

Table 2 summarizes the descriptive analysis of the 207 participants who completed the three tests. This analysis summarizes that the mean age of the subjects was 35 years, with the majority of subjects being 33 years old. The age range for the subjects was 18 to 66 years. The mean height is 165 meters, and the mode of height is also 165 meters. The range for the subjects' heights is 123 to 192 meters. The mean weight was 74 kg, with a mode of 70 kg, and the range for the subjects' weights was 41 to 116 kg. This analysis includes both males and females for the test.

This study initially conducted a one-way ANOVA test to assess the relationship between the three tests and determine if there are any statistical differences among them. The null hypothesis states that the "mean for each group is equal." The ANOVA test method is summarized in Table 3. The significance value is < 0.000, which is less than 0.05. Therefore, there is a statistically significant difference in the mean of the test values. The critical F value is 3.01, and the observed F value is 46.15, which is greater than the critical F value. Therefore, the null hypothesis is rejected because there is clear evidence that the means of the three groups are different.

Based on the test results, it is observed that the groups are statistically significantly different. But to determine which group is different from the others, further multiple comparisons are performed using the Tukey post-hoc method. The results are shown in Table 4 for the Tukey post-hoc test. The arrangement of tests in this analysis is as follows:

1. Bucket test
2. Mobile phone app
3. Virtual SVV test

It can be observed from the table that the p-value for all groups is less than 0.05, indicating a significant difference between the three tests.

Table 3. Summary of results for one-way ANOVA test

Method					
Null hypothesis		All means are equal			
Alternative hypothesis		Not all means are equal			
Significance level		$\alpha = 0.05$			
Information of Factor					
Factor	**Levels**	**Values**			
Tests	3	Bucket Test, Mobile Phone App, Virtual SVV Test			
Results of Test					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	182.605	2	91.303	46.158	.000
Within Groups	1222.440	618	1.978		
Total	1405.045	620			

Table 4. Test results for Tukey post-hoc method

Tukey HSD						
(I) Tests Type	**(J) Tests Type**	**Mean Difference (I–J)**	**Std. Error**	**Sig.**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
1	2	1.328*	.1382	.000	1.00	1.65
	3	.6688*	.1382	.000	.343	.993
2	1	–1.32*	.1382	.000	–1.653	–1.003
	3	–.660*	.1382	.000	–.984	–.335
3	1	–.668*	.1382	.000	–.993	–.343
	2	.660*	.1382	.000	.335	.984

Figure 5a displays the area under the ROC curve for the bucket test, with an area of 0.725. The test result variable(s) with higher values suggest stronger evidence of a positive actual state. Test results indicate that there is at least one tie between the negative and positive actual state groups. The statistics may be biased. Figure 5b shows the area under the ROC curve for the mobile phone app test, with an area of 0.283. The smaller values of the test result variables indicate weaker evidence for the positive actual state. Figure 5c shows the area under the ROC curve for the virtual SVV test, which is 0.492. This is the median value between the ROC curve values of the two tests.

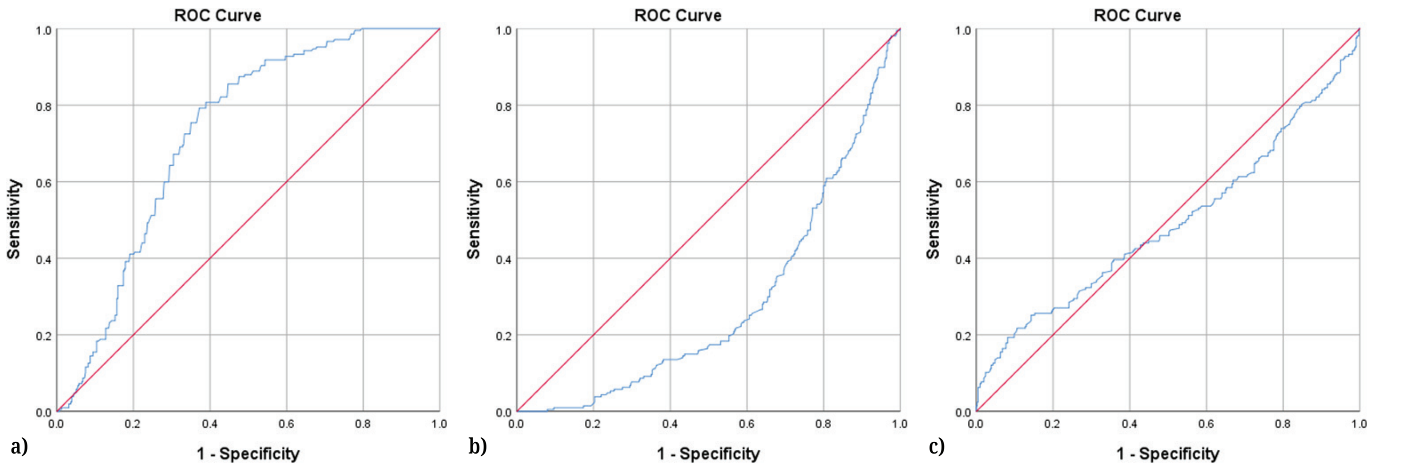


Fig. 5. ROC curve for (a) bucket test (b) mobile phone app (c) virtual SVV test

Correlation analysis examines the relationship among the three tests. Within the range of +1 and –1, a correlation indicates the degree of association or simultaneous occurrence between two variables. The correlation results for the test are presented in Table 5.

Table 5. Test results for correlation analysis

		Bucket Test	Mobile Phone App	Virtual SVV Test
Bucket Test	Pearson Correlation	1	.652**	.456**
	Sig. (2-tailed)		.000	.000
	N	207	207	207
Mobile Phone App	Pearson Correlation	.652**	1	.470**
	Sig. (2-tailed)	.000		.000
	N	207	207	207
Virtual SVV Test	Pearson Correlation	.456**	.470**	1
	Sig. (2-tailed)	.000	.000	
	N	207	207	207

5 DISCUSSION

This study conducted four types of analysis on the angle measurements of the three tests to identify any relationships or differences among them as well as to compare their performance. Firstly, a descriptive analysis is performed, which does not reveal any significant differences between the three groups. The descriptive analysis consists of measuring statistical parameters and creating graphs, such as box plots. The analysis was performed using the one-way ANOVA test to determine if there was any difference in the mean. The results of this test indicate a significant difference between the groups, as the p-value is less than 0.05 and the critical F value is lower than the observed F value, leading to the rejection of the null hypothesis. The next test is based on the ROC curve for each test comparison, using sensitivity and specificity. Better accuracy is achieved for a larger area under the ROC curve. The area under the ROC curve for the bucket test it is 0.72, for the mobile phone app it is 0.28, and for the virtual SVV test it is 0.48. Therefore, the bucket test has better accuracy compared to the virtual and mobile phone tests. In the last analysis, a correlation was performed to determine the relationship between the three groups. It is a statistical parameter that measures the extent to which these groups are linearly related. It is a commonly used tool for describing relationships. The results show that the correlation coefficient between the mobile phone test and the bucket test is 0.652, between the mobile phone test and the virtual SVV test is 0.470, and between the bucket test and the virtual SVV test is 0.456, with a p-value of 0.01, which is less than 0.05. Hence, the highest correlation coefficient is obtained between the mobile phone test and the bucket test.

Michelson et al. [36] compared the C-SVV goggles to the SVV bucket test using only healthy individuals. For the bucket test, the average SVV value was 0.81, while for the C-SVV goggles, it was 0.29. Due to the higher absolute stability of the test-retest, it was concluded that the C-SVV is a more exact and reliable tool for measuring the SVV compared to the bucket test. On the other hand, only two tests were compared, and they only involved healthy people. As a result, directly comparing the proposed method may be problematic, as we had individuals with three different tests. Furthermore, the average subjective vertical of healthy participants varies from one laboratory to another, and there is variation in the mean subjective vertical of healthy participants. Therefore, we can conclude that this study is more robust and reliable because it performed a comparison of three SVV tests using four different statistical analyses.

6 CONCLUSION

The SVV tilts have been reported to be a sensitive indicator of vestibular dysfunction, particularly in the otoliths, and can be found in peripheral or central problems in any vestibular pathway, from the labyrinth to the vestibular brain. The focus of this study is to propose a method for comparing the performance of three tests: the bucket test, the mobile phone test, and the virtual SVV test for emulating the SVV exam. Therefore, more efficient methods can be utilized in clinical practice. The research data included measurements from 207 subjects in eight trials for three different SVV tests. After organizing the raw data from the subjects, it is analyzed using the SPSS software. The statistical analysis includes four types of analyses: descriptive analysis, one-way ANOVA, ROC curve analysis, and correlation analysis. Based on the ANOVA test results, it is concluded that all tests are statistically significant with a significance value of $p < 0.05$. Correlation analysis also demonstrated that the highest correlation coefficient (0.65) is obtained between the mobile phone test and the bucket test. Hence, we can conclude that each SVV test is not the same. The performance of the tests is measured using an ROC curve, and the results indicate that the bucket with the highest ROC coefficient is 0.72.

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