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RESEARCH ARTICLE

The effect of head tilt angle in the roll plane on the virtual subjective visual vertical results in healthy adults

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Abstract

Background and Aim: The subjective visual vertical (SVV) is commonly considered as an indicator of the sense of orientation and attributed to the utricular function. The present study examined the impact of different head tilt angles on SVV among the normal individuals.

Methods: SVV was measured in 47 normal participants (30 males and 17 females; mean ± SD age: 22.14 ± 3.46) using a virtual goggle and forced-choice paradigm and was applied twice in 0º, 15º, 30° and 45º to the left or to the right. In addition, difference in mean of SVV in zero and non-zero positions was compared.

Results: There was a statistically significant difference between the mean SVV results of 0º and 15º ($p < 0.001$). The comparison of mean SVV results between 0º and 30º, and between 0º and 45º were not significant ($p > 0.05$). In addition, comparison of SVV results between rightward and leftward tilt of 15º was statistically significant ($p < 0.001$). The latter comparison was not significant for 30º and 45º ($p > 0.05$).

Conclusion: Our results showed that head tilt angle of 15º have a substantial impact on the virtual SVV. These findings must be taken into account in the growing body of research that uses the SVV paradigm in clinical populations.

Keywords: Head tilt angle; subjective visual vertical; virtual goggle; roll plane; utricle; healthy adults

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Introduction

Balance refers to the maintenance of body stability in static and dynamic positions [1]. Sensory inputs provided by somatosensory, visual and vestibular systems are necessary to maintain balance. The vestibular system, as a sensorimotor system, consists of two parts: peripheral and central, and has a significant role in maintaining balance in static and dynamic states by providing information about spatial orientation. Therefore, it is important to consider it as a mechanism that can affect balance and gait. Otolith organs (saccule and utricle) are mainly responsible for detecting linear movements and the direction of gravity in order to maintain postural control [1, 2]. Otoliths act as a sensor to determine the direction of gravitational-inertial vectors and are effective in navigating. Perception of verticality is one of the most important tasks of otoliths. The subjective visual vertical (SVV) test is a reliable

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test to assess the function of utricle and superior vestibular nerve [3,4]. In this test, the person is asked to return the inclined line to its upright vertical position by relying on his/her vision, and perceive that the image of the object is vertical to the gravity axis [5]. Peripheral and central vestibular lesions can produce an abnormal head tilt and/or ocular torsion that affects SVV results. These lesions can occur at any level of the vestibular pathways from the labyrinth to the vestibular cortex [6].

Perception of verticality is based on the integration of visual information with other sensory systems, including the vestibular and proprioceptive systems. In the vertical position, the inputs of proprioceptive system that regulate the position of the head and trunk naturally adapt to the gravity axis [7,8]. However, with deviation in the head tilt, deviation in retinal image occurs such that this image is in opposite direction to the tilt of the head. In fact, this compensatory response is much less than the amount of head tilt and leads to the deviation in retinal image [8,9]. Hence, head tilt can be a challenge to integrate vestibular and visual information for consistent and stable perception in the vertical direction, which is shown as systematic SVV errors when the head tilted in the vertical direction [10]. Moreover, any damage to the vestibular system information processing at any stage can cause a pathological deviation in the SVV test. This pattern is frequently used to identify unilateral and chronic vestibular defects [11,12]. However, lesions in the thalamus and damage to the cerebral cortex can also lead to a pathological SVV deviation. For example, a study by Brandt et al. [13] found that SVV deviation was present in 33 of 52 patients with brain injury in the parieto-insular vestibular cortex region. Most studies in patients with stroke, and especially in people suffering from hemi neglect syndrome, indicate an SVV deviation to the opposite side [14,15]. The SVV model has also been used to study other diseases such as paraplegia [16] and postural deviations [7].

However, even normal individuals have a deviation in SVV, and several studies have reported an average deviation angle of ± 2º [17,18]. Given the role that otoliths play in perceiving verticality, it is necessary to study the SVV test as much as possible in order to provide a suitable test battery for evaluating the otolith system.

In this study, we aimed to study SVV in normal adults and to investigate the effect of different degrees of head tilt on SVV values. By using the Virtual SVV software and hardware (Interacoustics, Middelfart, Denmark), while performing new experiments (especially those that are less considered in Iran) and presenting the norm range for the available population, we present a novel study (the effect of head tilt on the SVV test results). It is worth mentioning that so far no study has done on the SVV normality in the Iranian population. This study conducted to establish the values of SVV norms in both sexes (male/female). In addition, determining the normal range for SVV values in different head tilts, as a distinct aim of the present study, can distinguish between people who are in the normal range and people who are not in the normal range.

Methods

This is a descriptive-analytical study that was performed in the three first months of 2020 on 47 samples (30 males and 17 females) aged 18−35 years (mean age = 22.14 ± 3.463 years) living in Tehran referred to the Audiology Department of Rofeideh Rehabilitation Hospital. They were selected based on a convenience sampling technique and inclusion criteria which were visual acuity greater than 0.8 according to Snellen chart [18], without astigmatism, no history of ear-related diseases (e.g. hearing loss, external ear infection, and negative pressure in the middle ear), vestibular diseases (e.g. dizziness, postural disturbance, Meniere's disease, and migraine), neurological diseases (stroke, multiple sclerosis, Parkinson's disease and intracranial tumors), cardiovascular disease, metabolic and infectious diseases, chemotherapy, symptoms associated with mental and musculoskeletal disorders, as well as neck movement within the normal range of motion and no neck pain.

To perform the SVV test, the participant sits in a fixed chair at a specified distance from the

Fig. 1. The subjective visual vertical system (Virtual subjective visual vertical, Interacoustics) used in this study.

computer screen, while the binocular goggles of the Virtual SVV which creates complete darkness (Fig. 1), were over her/his eyes. Then, a luminous line was displayed inside the goggle, and the subject was asked to align the line in the vertical direction (gravity axis) by using the buttons on the hand controller of the device. In other words, by using the controller, the subject moved the line inside the goggle display left and right until the line was in the direction of the perceived gravity axis. In the first step, at a zero degree angle (head fixed looking straight), the subject was asked to align the line in the vertical direction, and then the head tilt was set at 15º, 30º and 45º in the SVV software to re-perceive the verticality at each of these angles, and finally the obtained data were recorded. It should be noted that the device was equipped with a gyroscope and showed the amount of head tilt from the vertical direction with an accuracy of 0.1º. Moreover, all these steps were performed twice in a situation where the subjects had binocular vision and the results in each step were presented and compared on average. To reduce the effect of the order of the tests on the final results, the first step was performed for all subjects, but the other steps were done randomly in different subjects. Each step of the head-to-right tilt was followed by the step of the head-to-left tilt and vice versa. Data analysis was performed in SPSS 23 software. In this regard, after confirming the normality of data distribution by Kolmogorov-Smirnov test, t-test was used for examining the difference between different head tilt conditions.

Results

Table 1 shows the effect of the head tilts to the right and left (15º, 30º and 45º) on the SVV values.

The results of paired t-test (Table 2) showed that when the head tilted to the right and left for about 15º, there was a significant difference in the mean SVV compared to the condition without head tilt ($p < 0.001$), but in head tilts of 30º and 45º, no significant difference in the mean SVV between two conditions was observed. The mean SVV at different symmetrical head-tilt angles is shown in Table 3.

As can be seen, when the head tilted to the right and left for about 15º, there was a significant difference in the mean SVV compared to the condition without head tilt ($p < 0.001$), but in the head tilts of 30 and 45º, no significant difference in the mean SVV between two conditions was acquired.

Discussion

The present study was performed to investigate the effect of different degrees of roll head tilt on SVV values in healthy adults. According to the results, in the initial position (zero degrees), the SVV deviation and data dispersion was at the minimum level (−0.645 ± 1.85). At 15º of head

Table 1. Mean, standard deviation, minimum and maximum subjective visual vertical values

Tilt angle	Mean	SD	Min	Max
Right 45°	−1.03	5.55	−17.70	8.95
Right 30°	−0.22	4.35	−12.05	9.75
Right 15°	1.03	3.12	−8.20	6.70
Zero tilt	−0.64	1.85	−4.45	3.20
Left 15°	−2.28	2.76	−9.60	2.85
Left 30°	−1.74	3.92	−12.60	7.50
Left 45°	−0.69	5.07	−15.15	8.65

Table 2. Comparison of subjective visual vertical results between right-left tilts in the same angles using paired-sample t-test

Pair	Mean (SD) difference	95% confidence interval of the difference		p
		Lower	Upper	
Right tilt 15° - left tilt 15°	3.32 (3.42)	2.32	4.32	< 0.001
Right tilt 30° - left tilt 30°	1.52 (6.85)	−0.49	3.53	0.134
Right tilt 45° - left tilt 45°	−0.64 (9.25)	−3.36	2.07	0.637

tilt (right and left), the mean SVV values also changed in the same direction, but the data dispersion was still low. In the 30º head tilt, the mean SVV values changed in the opposite direction approaching zero, and the data dispersion increased considerably. In the head tilt of 45º, the mean SVV values were deviated to the opposite direction of the head tilt again and data dispersion continued to increase. To sum up briefly, in the primary position of the head (zero degree), the SVV values are less scattered and are close to zero. For head tilts up to 15º, the mean SVV results tilt ipsilaterally (i.e. toward the head tilt); and for higher tilts (i.e. more than 15º), the mean SVV results deviate contralaterally (i.e. in the opposite direction of the head tilt). To justify the results, a few points can be considered.

First, SVV result in zero head tilt is a manifestation of asymmetry between left and right utricular organs. However, any head tilt during SVV test resulted in the manifestation of another utricular asymmetry; it means the asymmetry between medial and lateral portions of utricular macula [19-21]. Thus, this study was also touched this trade-off between lateral and medial stimulation of utricles.

Second, based on previous studies, in head tilts lower than 30º, the lateral part is more stimulated. In these angles, due to the opposite deflections of hair cells' stereocilia relative to the head tilt, the SVV shift is slightly contraversive (compared to the direction of head tilt). This slight shift called E-effect [21-24]. We have observed the inverse of the E-effect in our study (Fig. 1). It could be related to the method of measurement and the effect of ocular counter-rolling (OCR). As described above, the distance between target and eyes has decreased in our method, the virtual SVV, compared with the classic method of SVV measurement by a projected line on a remote monitor. In one hand, previous studies have raised the OCR as an explanation for the E-effect phenomenon [25]. On the other hand, it is found that OCR gains reduced for near objects [26]. Hence, the viewing distance and OCR gain can justify our findings.

Third, another reason can be due to the entrainment effect stated by Mezey et al. [27]. According to this effect, the rotation of the environment or visual stimulus in the roll axis leads to the rotation of the eye movements in the same direction of rotation. In fact, this rotation of the eye is a type of optokinetic movement. This effect is activated at a minimum rotation of 10º–20º and has nothing to do with optokinetic nystagmus. Thus, based on this effect also our findings could be justified. Moreover, in head tilts higher than 60º, the medial part of the tilted-side is more activated [21]. Therefore, the SVV shift should be ipsiversive to the direction of head tilt [21]. Although our tilts were less than 60º, we have also seen significant redirection of SVV between 15º and 45º.

Van Beuzekom et al. [28] evaluated the SVV for active body tilt. They assumed that greater involvement of proprioceptive system would alter the results of the SVV test. The test was performed on 6 normal individuals with normal static SVV and their body tilt ranged from −150º to +150º in the opposite direction (left and right). They concluded that, as the degree of tilt in the head and body increases, the mean values and standard

Table 3. subjective visual vertical results in each head tilt compared with zero tilt using paired-sample t-test

		95% confidence interval of the difference		
Pair	**Mean (SD) difference**	**Lower**	**Upper**	**p**
Right tilt 15° - left tilt 15°	3.32 (3.42)	2.32	4.32	< 0.001
Right tilt 30° - left tilt 30°	1.52 (6.85)	-0.49	3.53	0.134
Right tilt 45° - left tilt 45°	−0.64 (9.25)	−3.36	2.07	0.637
Zero tilt - left tilt 15°	1.64 (2.43)	0.92	2.35	< 0.001
Zero tilt - left tilt 30°	1.10 (4.20)	−0.13	2.33	0.080
Zero tilt - left tilt 45°	0.05 (5.66)	−1.61	1.72	0.949

deviation of SVV increase regularly; i.e. the data dispersion increases. Adjustment of SVV in healthy individuals is influenced by the roll-tilt angle; in tilts < 90º, the values of SVV test is estimated more than the real value (E-effect; “E” stands for Entgegengesetzt, that is “opposite” in German [29]); in tilts > 90º the SVV value is less than the estimated level (A-effect; “A” stands for Aubert effect); and at 135º, the SVV value reaches its maximum value. According to Van Beuzekom's study [28], although the mean values and standard deviation of SVV increase with increasing head and body tilt, it is within the normal range and there is no difference between static and dynamic states.

Ashish et al. conducted a study on 82 people (52 men and 30 women) in India by using SVV test in static and dynamic modes (rotation of the visual field). Their results showed that the mean values of SVV in static and dynamic states between men and women were in the normal range and there was no significant difference between them; by moving from static to dynamic state, their mean value and standard deviation gradually increased but were within the normal range [30].

One of the limitation of our study was the test that performed in a certain age range. The main problem in performing the SVV test is that it does not have a standard protocol; hence, causes obvious inconsistencies in the test instructions between different studies. In fact, the results of various studies cannot be generalized to all clinical practices. Another limitation of this study was that it had to be done in more tilt positions because more tilt had to be applied to the head and body to achieve the A-effect. However, in this study using virtual SVV, we reached the inverse E-effect in head tilt of 15º, which has not been reported in previous studies.

Conclusion

The subjective visual vertical (SVV) test provides us with appropriate diagnostic information, and by changing the test process from static to dynamic, the sensitivity of the test increases. We concluded that with increasing head tilt, mean values and standard deviation of SVV values change but are within the normal range; hence, this test can be used in clinical and diagnostic studies.

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Conflict of interest

The authors declared no conflicts of interest.

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