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The effect of head roll and soft surface on Virtual SVV in healthy subjects: A normalization study

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Abstract

Objective: The utricle is a crucial structure for a sense of gravity, but the contribution of proprioceptive receptors is also essential. This study aimed to measure the effect of head roll and soft surface on subjective visual vertical (SVV) in healthy subjects to determine the effect of neck and plantar proprioceptive inputs.

Methods: In the first experiment, 78 healthy subjects performed 0, 15, 30, and 45-degree head rolls to the left and right side while standing. Three measurements were performed in every position. In the second experiment, 40 healthy subjects performed the same head maneuvers on a 20 cm thick soft surface. The Virtual SVV system (Virtual SVV™, Interacoustics, Denmark) was utilized for all measurements.

Results: The mean SVV on a hard surface was -0.99±2.34 degree at 0°. The SVV deviation increased with increasing head roll angle. The head roll to the right on a hard surface resulted in significantly different SVV angles than the neutral position (p<0.05). There was no significant difference in left head roll positions except at 15° (p>0.05). SVV deviation increased on the soft surface. Nevertheless, there was no significant difference between the two surface conditions.

Conclusion: The new Virtual SVV system measures SVV accurately. SVV deviation in the neutral position is similar to published results. However, under stress conditions such as with head roll and on a soft surface, every clinic has to set their normative data before comparing patients.

Keywords: Otoliths, utricle, subjective visual vertical.

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Introduction

One of the important functions of the balance system is to hold the center of gravity within the limits of the base. The whole vestibular system is responsible for this function, but the proprioceptive receptors and otolith organs play a major role. The otolith organs, utricle and saccule, are responsible for sensing linear acceleration, however, their anatomical shape is not limited in a definite plane. It is usually accepted that the utricle is responsible for linear accelerations in the horizontal plane, whereas the saccule is affected by vertical accelerations. The importance of otolith organs in vestibular disease has become of more interest every year, and test batteries have included routine tests of the otolith organs. It was shown that otolith organs are involved in both acute and chronic stages of vestibular diseases.[1,2]

Many different test methods are used for testing otolith organs, including vestibular evoked myogenic potentials (VEMP), linear acceleration systems, measuring the torsional movement of the eye by head rolling, frame and rod test, subjective visual vertical (SVV) and horizontal are some examples.[3,4] The bucket test is the most widespread application of the otolith test, which depends on the SVV. The bucket test can be performed easily in daily routine, however, standardization poses a significant challenge.[5] SVV is the angle between the adjusted vertical by the subject and the true gravitational vertical. Cohen et al. [5] reported low receiver operating characteristics values for the bucket test and decided that it was not suitable for screening patients with vestibular disease. Different methods like the head roll were proposed to enhance sensitivity.[6]

Technological improvements facilitate establishing more reliable tests. Bagust [7] used computers for classic rod and frame tests. Docherty et al. [8] published an improved version of the computerized rod and frame test. After virtual reality technology came to the market, many systems were studied for SVV.[9-12] One of these applications was the Virtual SVV system by Interacoustics. There are a limited number of studies with this system. Mueller et al. [12] tested healthy subjects for normative data and compared them with VEMP. They found a weak correlation between Virtual SVV and VEMP. Also, a comparison with the bucket test was performed and repeatability was found to be better.[13]

Even though normative data are included in the system software, previous experience shows that test conditions affect the test results. When a novel system is established,

there are many difficulties with standardization including the thickness of the light bar, the softness of the surface or the shoes, the haptic sensation of the hand, precision of the controller, quality of the reflecting wall, and position of the subject were difficulties to overcome. Therefore, we decided to test the new system under normal and stress conditions to standardize our test settings. In the present study, our purpose was to establish normative data during proprioceptive stress conditions like a head roll at different angles or standing on a soft surface.

Materials and Methods

Healthy adult volunteers were invited for two consecutive experiments. All volunteers were subjected to a detailed history and ear examination. Subjects who had ear disease, history of vestibular or neurologic disease, ear, brain, or musculoskeletal surgery, or ototoxic drug use were excluded from the study. Written informed consent was obtained from all participants after describing the procedure. 78 subjects were involved in the first experiment, whereas 40 subjects were included in the second experiment. The institutional ethics committee approved the study with project number of 60116787-020/60326). The study was registered to clinicaltrials.gov (NCT04396132) retrospectively.

Intervention

Virtual SVV is commercially available on the market (Virtual SVV™, Interacoustics, Denmark). The system consists of goggles, a computer and a handheld controller. When the patients put on the goggles, they can only see a light rod on the screen. No light can enter the goggles. The goggles have a sensor that detects the angle of the head. The starting point of the rod can be adjusted to different angles by the computer in a random manner. The subject has to adjust the rod in the vertical position using right/ left arrow signs on the controller. When the verticality is confirmed by pushing the set button in the middle of the controller, the computer records the rod's angle and the position of the head. Every test was repeated three times with five second intervals. When the subject finished the normal SVV at 0° angle, they rolled their head to the right or left 15°, 30° and 45° and tried to adjust the rod again. The average value was recorded after testing the angles three times. A total of seven tests were performed at different head roll angles.

Two different experiments were performed in the pres-

ent study. In the first experiment, volunteers stood on a hard surface and did a head roll. In the second experiment, the subjects stood on a soft surface, 20 cm thick foam rubber, and did a head roll.

Statistical analysis

SPSS version 21.0 (Statistical Package for the Social Sciences Inc., Chicago, IL, USA) was used for statistical analysis. Continuous parameters were plotted as mean ± standard deviation, median, minimum and maximum values, while interquartile intervals were plotted on the figures. Paired samples T-test was used for testing intragroup differences due to different angles of the head roll. Categorical variables were plotted as numbers and percentages. Kruskal Wallis variance analysis and post hoc Mann Whitney U test with Bonferroni correction were used to compare hard and soft surface groups. A p value less than 0.05 was considered statistically significant.

Results

A total of 118 volunteers were included in the present study. 78 (44 male and 34 female) were involved in the first experiment. They stood on a hard surface and rolled their head right and left at various angles. The mean age of the first group was 25.4±7.8 years. Forty subjects (21 male and 19 females) with a mean age of 24.23±6.75 years participated in the second experiment. They stood on a soft surface while rolling their head right and left at the same angles.

The SVV measurement of the patients showed a broad distribution (Figure 1). When the angle of the head increased, the variability of the SVV angle increased. The patients did not have any difficulty while following the head roll instructions. There was no difference between right and left roll reactions (Figure 2). The mean SVV deviation was -0.99±2.34 in a neutral position (0°) on a hard surface. When the subjects rolled their head to the right, the SVV increased. The mean SVV was measured as 0.48±3.76, -2.26±5.08 and -5.06±7.14 at 15°, 30°, and 45° head angles consecutively. The head roll to the right on a hard surface resulted in significantly different SVV angles than the center position (p<0.05). However, the left head rolls were not as effective as the right ones. The mean SVV was -1.94±4.06, -1.01±5.78, and -1.02±8.09 for 15°, 30°, and 45° head angles, respectively. There was no significant difference in left head roll positions except at 15° (p>0.05)

The mean SVV at a 0° head angle was increased (-1.42±1.99) while the subjects were standing on the soft surface. Unlike the hard surface experiment, only 45° right and left head roll resulted in significant SVV deviation from the center position (p<0.05). There was no difference between the 0° head angle and other left or right head angles (Table 1). There was no statistical difference between patients standing on the hard or soft surface except at left 45° (p<0.05). When the data was analyzed in detail, there was a left deviation tendency of SVV at every angle except a 45° left roll in both groups (Figure 3). The median and interquartile range of the middle 50% were plotted in Figures 4 and 5.

Table 1. Mean and standard deviation of SVV measured at different angles. The actual head angle means the measured head roll angle during the test measured by the headset.

Head Roll	Group 1 (mean±std) (n=78)		Group 2 (mean±std) (n=40)	
	Actual Head angle°	SVV angle°	Actual Head angle°	SVV angle°
Right 45°	40.71±3.16	-5.06±7.14*	40.39±3.35	-6.35±8.58*
Right 30°	26.86±3.27	-2.26±5.08*	27.17±2.78	-2.72±5.55
Right 15°	14.26±2.94	0.48±3.76*	15.15±2.95	-0.192±3.47
Center 0°	0.19±2.69	-0.99±2.34	0.42±2.72	-1.42±1.99
Left 15°	-15.39±3.27	-1.94±4.06*	-15.5±3	-1.49±4.61
Left 30°	-27.33±3.07	-1.01±5.78	-27.06±2.71	-0.03±7.34
Left 45°	-41.11±2.86	-1.02±8.09	-40.38±3.53	2.63±9.48*

*Statistically significant when compared with the neutral position in the same group. There was no difference between groups except left at 45°.
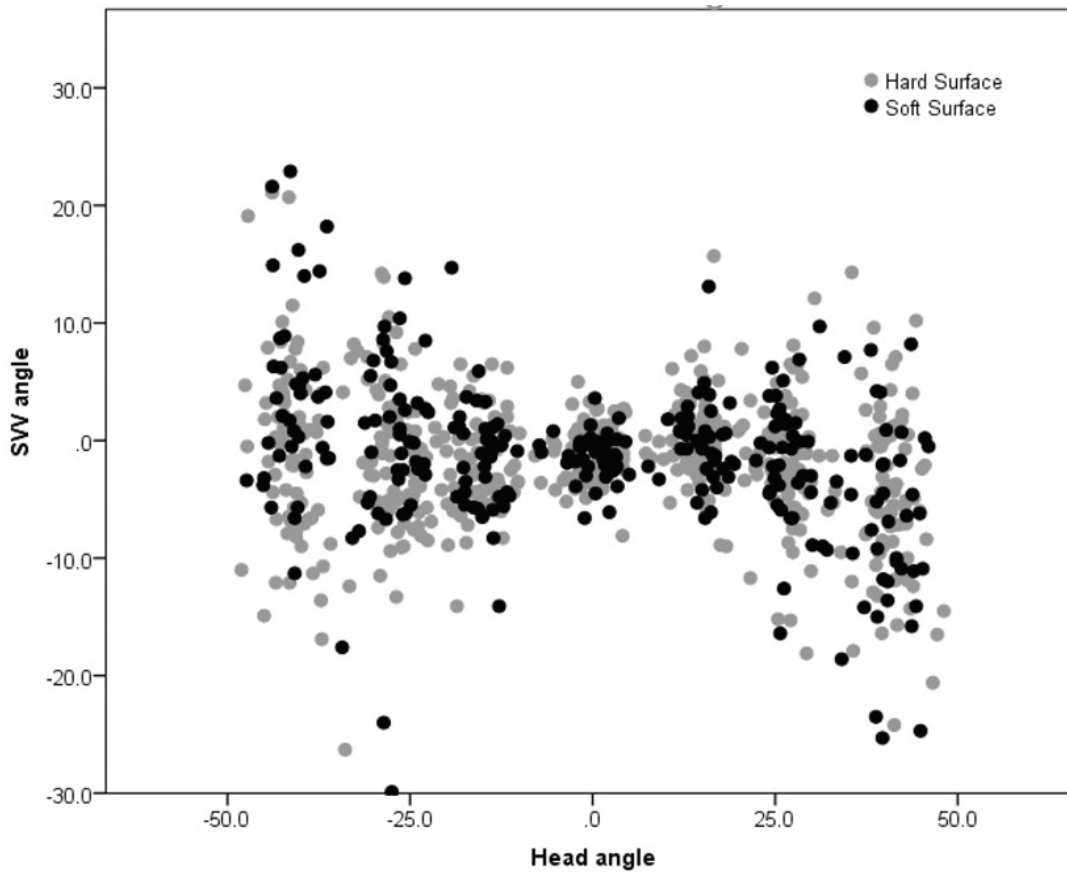
Figure 1. All patients were plotted on the scattergram. The distribution was similar for both soft and hard surfaces.
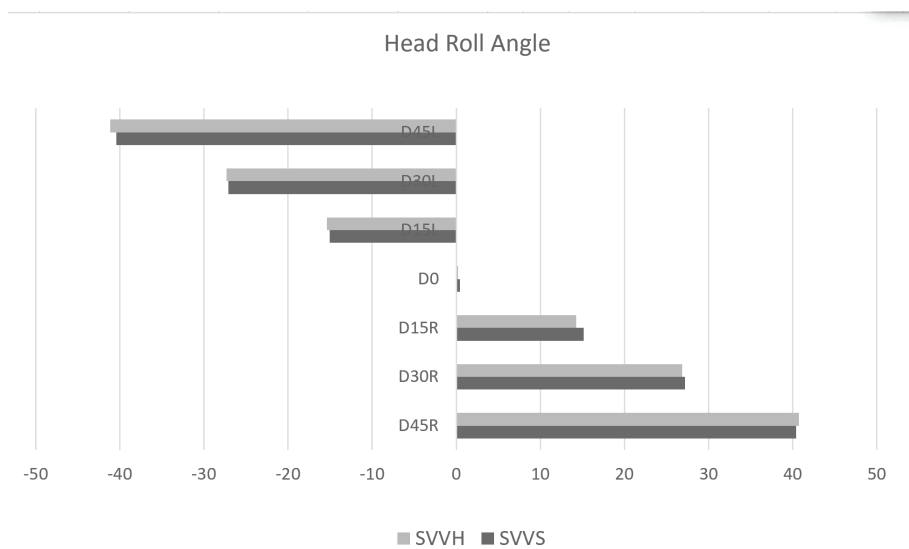

Figure 2. The headset's actual head roll angles when patients were trying to adjust certain test angles. Their compliance was good (p>0.05). (SVVH: SVV on a hard surface, SVVS: SVV on a soft surface).
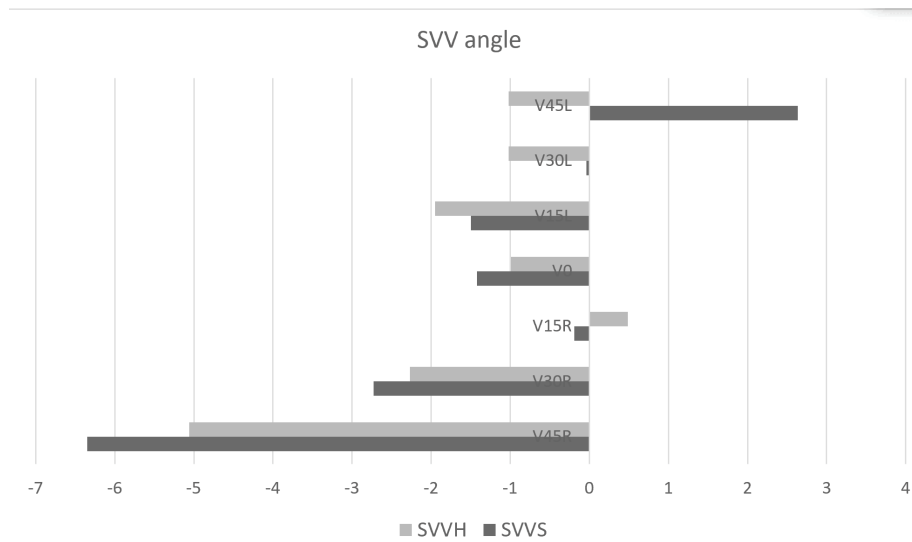
SVV angle

Figure 3. Mean SVV of right and left head roll tests. The head roll to the right on a hard surface resulted in significantly different SVV angles than the center position (p<0.05). There was no significant difference for left head roll positions except at 15° (p>0.05). While they were standing on the soft surface, 45° right and left head roll resulted in significant SVV deviation than the center position (p<0.05). (SVVH: SVV on a hard surface, SVVS: SVV on a soft surface).
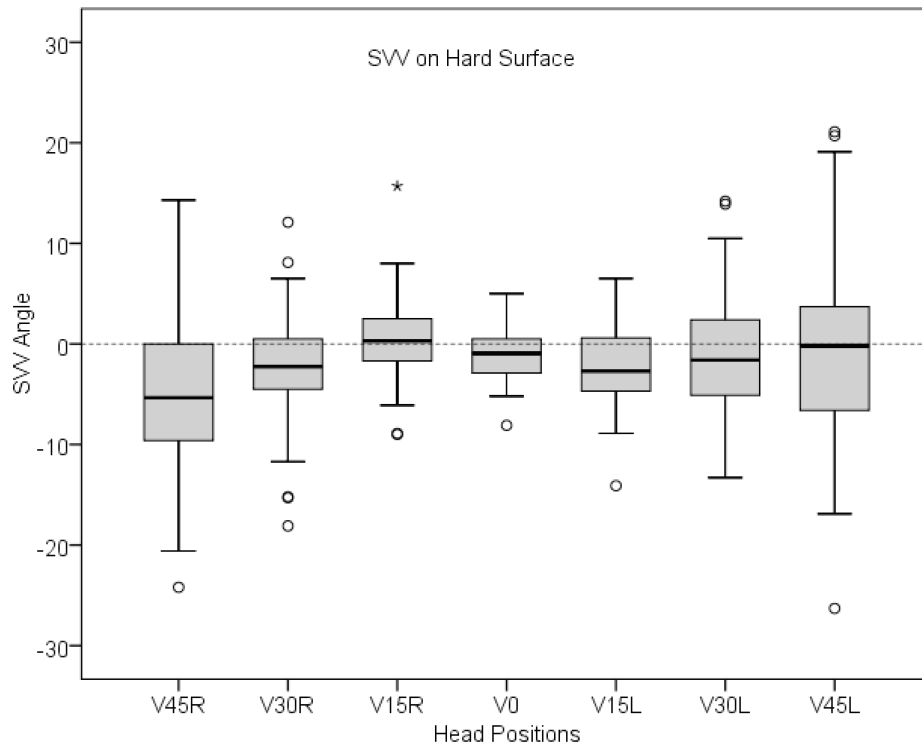

Figure 4. Box plot of Virtual SVV on a hard surface. Mean± interquartile range, minimum, maximum and extreme points are shown. (Ex: V45R means head roll 45° to the right, V30L means head roll angle 30°to the left).
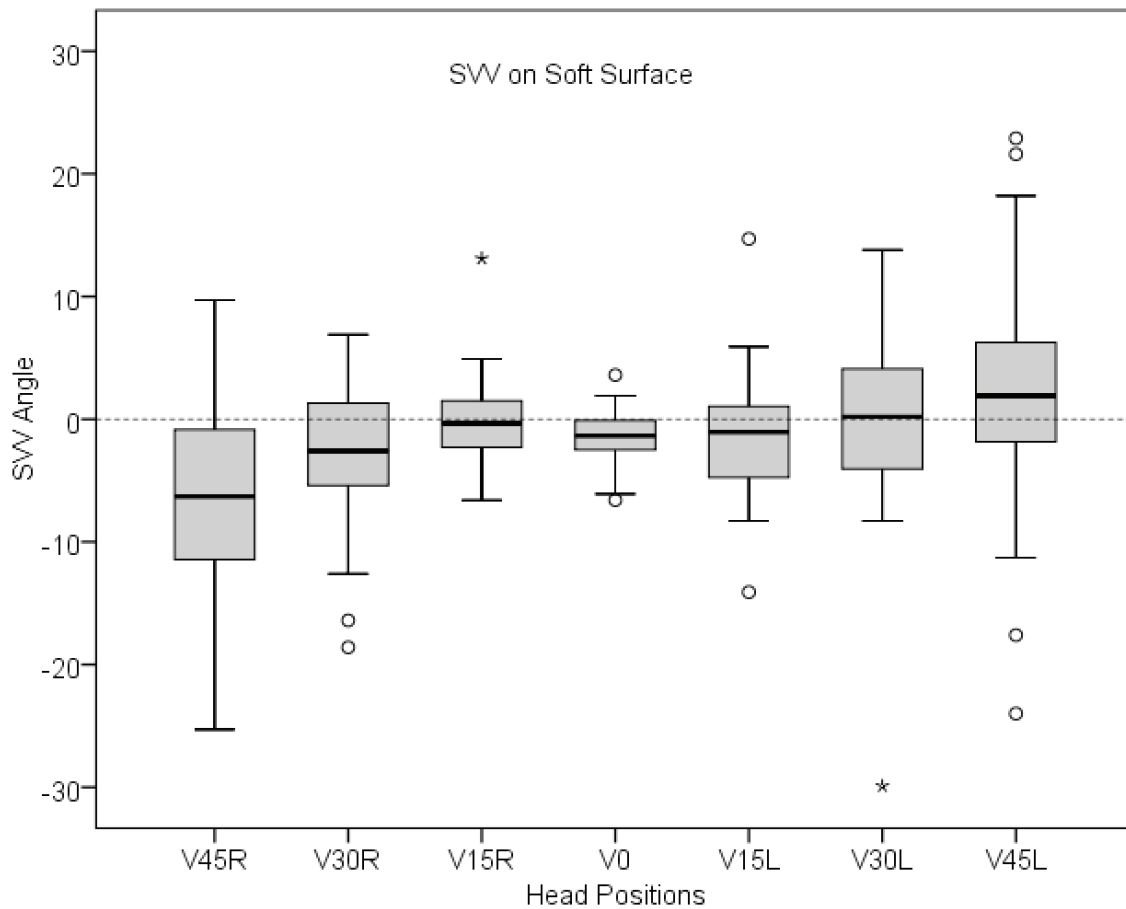
Figure 5. Box plot of Virtual SVV on a soft surface. Mean± interquartile range, minimum, maximum and extreme points are shown. (Ex: V45R means head roll 45° to the right, V30L means head roll angle 30°to the left).

Discussion

We investigated the effect of head roll and soft surface on SVV. We found that the SVV deviation was -0.99±2.34 when the subject was standing in a neutral head position. When subjects changed the head roll angle, the SVV increased, especially for the right head roll. There was a statistically significant difference between the neutral position and head angles to the right while subjects were standing on a hard surface. For the left head roll, there was no significant difference in SVV angles except at 15°. When the subjects were on the soft surface, the extreme head roll angles (45°to the left or right) created a statistically significant difference from the neutral position (p<0.05). There

was no statistically significant difference between standing on the hard or soft surface except left at 45°.

Mueller et al. [12] formed normative data for Virtual SVV with healthy subjects. They found that SVV was -0.197±1.72 in the upright position while the subjects were sitting. They also reported that normative data were diversified more when the roll angle increased either to the left or to the right. Our subjects were standing during all experiments. Therefore, our subjects relied on proprioceptive clues from the base of the foot only. A soft surface was also used to make it harder in the second experiment. Michelson et al. [13] tested the repeatability of Virtual SVV and compared it with the Bucket Test. They found a mean

SVV of -0.48±2.52. They concluded that Virtual SVV had better repeatability than the bucket test. Another virtual system built on the Oculus Rift program was also tested to detect the effect of static and dynamic visual conditions. They reported that it was a reliable measure in distinguishing patients from healthy subjects.[11] The mean SVV in the neutral position was -0.99±2.34 while subjects were standing. Normal values were more dispersed in our study. The difference might be due to the test condition since our subjects were standing while their subjects were sitting. In our study, increased dispersion was also observed when the subjects rolled their head to either side.

An interesting observation in this study was a shift in all values to the left side independent of the side or angle of the head roll. Michelson et al. [13] also found an overestimation to the right when the head was tilted to the right and vice versa. Typically, roll-tilted subjects at large angles have a false notion that leads them to adjust SVV deviated toward the tilted side in darkness. This is called the Aubert or A-effect.[14] At smaller angles (<30°), there is a deviation opposite to the A effect called the Müller or E effect.[14] The E-effect was observed in accordance with the literature when the heads were tilted to the right side. However, a small unexpected A-effect was present when they tilted their head to the left side. Tarnutzer et al. [15] reported errors and bias depending on the roll-angle after returning to the upright position. In their experiment, subjects adjusted the SVV after they had their head tilted 5 minutes on the same side at different angles and immediately after returning to the upright position. They found a significant drift to the roll side in 47% of the measurements. They concluded that SVV was not stable and changed according to the subjects and roll-angle.[15] The central mechanisms of prior knowledge of gravity accounted for this bias. Mittelstaedt proposed a model for the central vertical processing called the M model.[16] He thought that an idiotrophic (head-fixed) vector was added to gravitational signals coming from otoliths to adjust verticality and prevented E-effects at small angles. However, it also caused a bias that SVV deviated a little to the side of the head tilt.[14] Kaptein et al. [14] tested nearly all body tilt angles and reported that up to 135° the M-model was consistent. Nevertheless, common tilt sensation was dominant at larger angles. Subjects were tested in a neutral position first, then they were tested at head right angles. They had several consecutive tests with head roll to the right while standing. Depending on the Tarnutzer hypothesis with the M-model, the total duration of the right head roll tests might be long enough to build a new idiotrophic (head-fixed) vector, so when we continued with left tests, we observed a right bias + E-effect. This could be a systematic error due to the experimental setup. This kind of distribution would not be seen if the subjects would have been tested right and left consecutively one test at a time. Interestingly, the E-effect would disappear if the light bar was adjusted parallel to the head angle.[17] The starting point of the rod was also random in our experiment.

The effect of semicircular canals was omitted in the M model. Pavlou et al. [18] investigated the SVV change during the rotational test on the earth's vertical axis. SVV tilted the opposite of the rotation direction when the subject's head was in an upright and backward position. They claimed that this effect was mainly due to the posterior semicircular canal. This hypothesis was supported by the study on the SVV test with caloric stimulation.[19] They did not find any effect of the horizontal canal on SVV. Vingerhoets et al. [20] also measured SVV under constant velocity rotation and concluded that egocentric bias was more dominant than the idiotrophic vector under dynamic conditions. Unlike the other studies, the subjects stood on their feet in our experiment, which might have created a dynamic condition in our test setup. We did not know the detailed history other than our exclusion criteria. For example, birth history and sports habits could affect the outcome. It was reported that SVV and postural stability were impaired in preterm born children.[21]

It is believed that SVV has a limited sensitivity for centrally compensated disease, however findings of the present study showed that there were SVV abnormalities in the long run.[1] When the perception of verticality fails, postural instability is the most common symptom, and it is also a significant factor for falling. A study on Parkinson's disease is a good example of this relation.[22] Pereira et al. [22] found a good correlation between postural instability and SVV in idiopathic Parkinson's disease.

One of the important factors to maintain the verticality of the body is afferent proprioceptive input. Studies show that visual, somatosensory and vestibular inputs together form an egocentric body position image in the central system.[23] Maibraba et al. [24] studied SVV and postural vertical with patients with no somatosensory sensitivity, and they found bias on postural vertical towards the starting side but no change in SVV. Yardley reported a patient with no somatosensorial sensation below the neck. The patient adjusted SVV normally while sitting, but an E-effect was

observed when lying horizontally, in contrast to the A-effect in normal subjects.[25] Alghadir et al. [26] designed an experiment to test the effect of body posture on cervicocephalic kinesthesia. They found that if the weight of the arms was unloaded (put on an armchair while sitting), cervicocephalic kinesthesia was improved in both vertical and horizontal planes, so the proprioceptive input is about the head position. In our study, subjects were standing during the experiment while holding the handpiece mostly in their right hand. This might also have an effect in the systematic bias in our experiment. Faralli et al. [27] used a soft surface as a provocation input for SVV and concluded that the improvement of SVV in patients with unilateral vestibular dysfunction might be due to the increased effect of proprioceptive input from the plantar surface of the foot.

One of the limitations of our study was the lack of the dominant hand side in our records. The standing posture of the subject was also not standardized. The starting angle of the rod was not controlled, it was chosen randomly by the program. The handheld controller might also be a factor as a haptic clue or weight showing the direction of gravity.

Conclusion

The sensation of verticality is an important factor for postural control. Although many different inputs contribute to the system, SVV is a practical test that assesses the visual part of the gravitational vertical. Our findings showed that SVV could be easily performed in a short time. The an-

gle of SVV was also affected by the head roll angle. Even though the angles in both directions increased with a soft surface, there was no statistically significant difference between the subjects standing on hard and soft surfaces. It could be speculated that neck proprioceptive inputs were more effective than plantar inputs. Proprioceptive inputs need to be studied further to make clear their contributions to SVV.

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