Analysis on the optimal horizontal eye position as well as the effectiveness of a new system for video head impulse test

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Abstract

Objective: To identify an optimal gaze angle for precisely evaluating the function of vertical semicircular canals in video head impulse test (vHIT) and draw a comparison on the performances among three different systems for vHIT. Design: Two-center prospective study. Setting: Participants were sit 1.2 meters away from the wall in a noise-proved room that dedicated for vHIT experiments. For the gaze-angle projects, targets were placed on the wall sequentially at the pre-marked lines for different angles. During the comparison experiments, similar settings were ensured in both hospitals, like distance to wall and angle of staring. Same examiner performed the comparison between two systems in one location. Participants: 26 healthy participants were recruited in the gaze-angle experiments, 16 of which were further involved in inter-examiner tests. For the comparison projects, 9 and 13 participants were recruited, respectively. Any participant with otologic or vestibular disorders was excluded. Results: Our research showed that instead of right ahead at 0 degree, when torsion applied at vertical semicircular canal planes, 25-degree is a better place to set the targets. At this angle, a more accurate VOR gain was easier to be obtained. Besides, our evaluations of three different systems showed that a new vHIT system, VertiGoggles? ZT-VNG-I (VG) performed as good as the long-tested Otometrics?ICS impulse (Oto) and EyeSeeCam? (ESC). Conclusion: We proposed a new protocol to set the targets 25 degrees from right ahead after tilt head 45 degrees to evaluate vertical canals during vHIT. Furthermore, the new VG system is good for clinical practices.

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Key Points:

1. Increasing attention paid on vertigo complaint in otolaryngology clinics.
2. Effective assessments and quick diagnosis of vestibular disorder are essential for clinicians.
3. Video head impulse test (vHIT) is a standard and repetitively test to evaluate functions of the semicircular canals.
4. 25 degrees rather than conventional 0 degree is a better gaze angle while performing vHIT on vertical canals.
5. Cross-centers comparison of three vHIT systems indicated a new system with a new kind of goggle is able to perform as good.

Introduction

Vertigo is a common complain of patients that visiting otolaryngologist's office. With a lifetime prevalence of 7.8%, patients experienced vertiginous symptoms, such as dizziness, imbalance, sense of spinning, and loss of coordination, which have large impact on their daily life (1, 2). Not only to individuals, these imbalance problems also bring considerable cost to healthcare system and society. As an apparatus of inner ear, the vestibular system is composed by two otolith organs and three semicircular canals (3). Semicircular canals are perpendicular oriented to each other to sense angular acceleration in three dimensions (Figure 1). In the clinics, since the beginning of the 20th century, efforts were made to evaluate the function of semicircular canals. Caloric test (4, 5), electronystagmography (ENG) (6), and head-impulse test (HIT) (7) are introduced during the years that still widely used in today's practices to locate the defected vestibular organ.

Among the different tests, recently, the vHIT has been considered as the standard even the initial test since it is applicable repetitively in a short interval to all six semicircular canals (1). A passive, unpredictable, fast angular head movement (>150°/s) is applied to activate a specific pair of semicircular canals (8) (Figure 1). Coordinately, eyes are able to move against head through the vestibular-ocular reflex (VOR), to stabilize the image on the retina. During the tests, the relative of eye movements to head movements is recorded as the gain of VOR to assess the vestibular system. Damaged semicircular canal will not be able to move eyes against to head during the test, then the patient has to make a corrective saccade at the end of head impulse. During the practices, the results of VOR gains for vertical canals usually arise controversy due to the technical complications. First of all, the recording is binarization of a 3-D movement that need carefully align the testing parameters for vertical and torsional components to avoid noises (Figure 1A and C) (9). The pupil was driven toward the eyelids while performing the vertical impulses, in which case, eyelid obscures part of the pupil that diminished the vertical gain recorded. Efforts were made to find an optimal staringposition to minimize the adverse effects. Previous paper found that with the increased of gaze angle on the horizontal plane away from right-ahead, the measured vertical VOR gain decreased (10). However, this is not we found in daily practices that with one eye open and head tilted 45 degrees to ensure impulses at vertical canal planes, patients are hard to stare at the targetduring head torsions, which attributes to mixed outcomes that obscure the real defects (Figure 1D).

In addition to the gaze angle, another concern about the frequently-used vHIT systems was raised. The goggle that was used in some vHIT systems could only record VOR from the right eye. The inconvenience raised from some patients hard to see the straight targets when head tilted especially to the right. Besides, it is even harder to record when any patient suffered a right eye damaged or defected. In this case, a goggle that can record VOR gain from either eye is needed. The new system, VertiGoggles? ZT-VNG-I (VG) provides this kind of google to eliminate the inconveniences. To improve the protocol of vHIT, we first tried to find a more suitable gaze angle on horizontal plane to obtain a better VOR gain to perform the vertical impulses. Furthermore, to make sure the new goggle and vHIT system has as good effectiveness as the existed popular systems under various conditions, we started a two-center project to compare between VG system to the long-standing vHIT systems. Our results demonstrated that staring at 25 degree has a higher VOR gain in vertical canal vHIT. Besides, the new kind of goggle offered comparable or even better vHIT results, especially when head tilted to right.

Materials and methods

Subjects

Healthy participants excluded any otology disease nor vertigo complaints were recruited in our experiments. When compared the three systems at two different clinical center, 9 and 13 participants were recruited, respectively. For the gaze angle experiments, we had 26 participants, 16 of whom we performed the inter-examiner evaluation. The informed consents were obtained from the participants. The experimental procedures in our study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

System settings

For the gaze angle experiments, comparisonbetween VG and Otowere performed in Shanghai Changzheng Hospital, while the tests between VG and ESC were performed at Fudan University affiliated Eye and ENT hospital. In either experiment, we were inclined to record from right eyes. Recording from the left eye only if the patient could not see the target from the right eye. All the experiments were applied by the trained examiners.

Experimental procedures

Participants in different centers were tested in identical surrounding settings. The room was lit and noise-proved. A non-rotatable wooden chair was fixed at a certain spot for participants to sit 1.2 meters (m) away from the wall. All goggles are tightened firmly to avoid any kind of slippage. Each kind of goggle carries a high-speed digital camera and a gyroscope to catch the movements of pupils and sense the angular acceleration. Each equipment was calibrated according to the manufacture's guidelines. We defined the straight-ahead when facing the wall is 0 degree. From this point on, the 15, 25, 35, and 45 degrees was marked. We pre-calculated and draw a perpendicular line of each angle on the wall (Figure 1F). The targets were placed on the perpendicular lines according to the participant's height. When performing the vertical impulses, participants tilted their heads 45 degrees away while keeping their eyes on the targets at 0, 15, 25, 35, and 45 degrees, respectively.

Searching the best gaze angle, only the vertical semicircular canals were tested. All directional degrees were collected on the two pairs of vertical planes. After distracted the participants' head 45 degree to the right, we asked them to stare at the targets that placed at 0, 15, 25, 35, and 45 degrees sequentially. At each angle, at least 10 successful impulses were recorded after outliers were excluded. After the right-side experiments finished, we turned their heads to the left, to perform another round of tests.

In contrast, all six semicircular canals were tested with eithervHIT system in the comparison project. We first asked the participants to look straight forward at the target and move the head at ground-parallel plane to test the horizontal semicircular canals. Then we followed the manufactures' instructions when performing vHIT on LARP and RALP planes. In the VG and Oto systems, we turned the participants' head 45 degree left or right with the anterior-posterior axis fixed, while their eyes stared at the same target. For the ESC system, we kept the participants' head at straight-ahead but rotated side- upwards and downwards. To perform the inter-examiner tests on the gaze-angle experiments, we have two independent examiners to performed on the same participants.

Data analysis

The VOR gain was obtained based on different system settings. To analysis the gain from gaze-angle experiments, since we repeated performed the vHIT on the same participant, we performed the one-way repeated measure ANOVA on the data from different angles, with the angle as the variable of interest. We further check the assumptions with the R function. The level of statistical significance was set at p <0.05, which means the angle contributed to the significant difference between groups. Then we performed Bonferroni test between data of each angle to 0deg to determine which group(s) was significantly better than 0deg.

To evaluate the inter-examiner differences, we performed limits of agreement (LOAs) and Bland-altman plots to compare the distributions of values and statistical differences.

For the comparison experiments, we aimed to compare VG respectively to Oto and ESC, rather than in between all three of these systems. Thus, we applied t-test analysis on either VG to Oto and VG to ESC with SPSS software.

Results

Experiment 1. Different from theoretical model and existing data, the VOR gain manifested as a bell curve with angle increased

Among the daily tests, certain number of patients complain that they can't stare at the target right ahead when head tilted 45 degrees away. In this case, we first investigated which angle is better to stare when their head position was insured. To carry out this experiment, we applied the head impulse of each vertical semicircular canal while asking the participants to gaze at targets at 0deg, 15deg, 25deg, 35deg, and 45deg (Figure 1F). As claimed by the existing data and protocols (10), VOR gain should be decreased with angle increased that 0 degree has the highest gain. However, different from expectations, during our tests, the VOR gains displayed rather a bell curve with angle increased. The gain was increased with the gaze angle increased that reach the peak around to 25deg. For the left anterior (LA) and left posterior (LP) canal, highest gain was obtained at 25deg. The best angle for right anterior (RA) and right posterior (RP) canal was 15deg and 35deg, respectively.

To understand if the angle caused a significant difference of VOR gain, we performed one-way repeated measure ANOVA analysis. Our data demonstrated the gaze angle do lead to statistical significance on the VOR gain (Figure 2). We further analysis which angle was significant better. The results revealed that 25deg has the lowest p-value for LARP and LP plane. For the RA plane, the 15deg was significant better. Given the uniformity requirement during clinical practice, we proposed a new gaze angle at 25deg during vHIT on vertical semicircular canals. Placing the target at 25 degrees away from right-ahead after tilted the head of patients to 45 degrees will give the examiners a more accurate result.

To exclude any system bias, we conducted an inter-examiner test. Two independent examiners were recruited to performed the vHIT on the same participant, respectively. Our results indicated that there were no differences in VOR gain of either semicircular canals between examiners (Figure S1).

Experiment 2. As good performance of VG on vHIT compared to Oto and ESC systems.

To test the efficiency of the new goggle that could record from either eye and further evaluate performances of the new vHIT system, VertiGoggles? ZT-VNG-I (VG), we conducted a two-center clinical project in comparison to the longstanding systems, Otometrics?ICS impulse (Oto) and EyeSeeCam? (ESC). Given that the experiments were carried out separately, we applied the t-test to analyzed our data (Figure 3 and Table S1). First of all, there was no significant difference found in between the systems on the lateral semicircular canals, which indicated the stability and reliability of this plane across systems. However, differences showed up on the vertical canals. For the RALP plane, the VOR gain were similar between VG and Oto. But VG showed significant difference in comparison to ESC that the gain was closer to 1 with smaller variations. Furthermore, for the LARP plane, three systems performed similarly on the LA. But the results of VG were different from either Oto or ESC on the RP canal. The VOR gain we obtained from VG was closer to 1 with less standard deviations in either comparison. Our data indicated three systems has comparable performance in vHIT. Besides, with the convenience provided by the new goggle, the VOR gain from RP canal is recorded even better.

Discussion

Previous paper claimed that relationship between the VOR gain and horizontal eye position was inversed (10). This was similar to the theoretical model that the VOR gain is calculated as$\text{Cos}\,(\text{gaze angle}) * \textit{eye ball radius}$indicating the vertical movement of eye during the head impulses on vertical canals (Figure 4). However, during clinical practices, especially when performing vHIT with Oto system, patients hard to follow the targets during the vertical impulses when head turned 45 degrees away.

In our investigations, we combined the VOR gains from all different vertical plane at different angles together, before compared it to the theoretical model (Figure 4A). This comparison revealed that the 25deg has the best gain that most significant different from 0deg. One explanation we had was the range of pupil movement when staring at the 0deg was shorten by the canthus and eyelids (Figure 4B-F). Even instructed the participants to open their eyes up, the relative distance of pupil shift was cut. Moreover, most of the time, patients can't open their eyes large enough for systems to detect the real eye position, which usually were underestimated the eye movement (Figure 4E). Even though pupil movement would not be blocked at 45deg, the VOR gain was decreased, which agreed with previous data that suggested decreased oculomotor kinematics at 45deg affected (10). Thus, we proposed that different from "ideal" situation and previous papers, 25deg is a better gaze angle when practicing vertical vHIT.

Similar to formerdata, ESC performed less well on vertical semicircular canals (1). In contrast, Oto was considered as a gold standard system by former investigations (1, 11). We compared the new device to either of these systems. Our results showed that first of all, the pupil detection system with the newly reformed goggle worked just as fine. Secondly, different from Oto system, the new goggle allows the patients at LARP plane, especially, to stare at the targets easier. This convenience not only leads to a better result on the RP plane, but offers examiners the freedom to pick whichever eye for VOR tests. In a word, this newly build VG system performed as good as Oto, even better than ESC system.

With the limitations of our experiments, there are still several directions that we would like to investigate in the future. First of all, our hypothesis was performed with limited participants recruited. It would be better to test this modified protocol with broader subjects. Furthermore, we would like to test the VG system out in vertical semicircular canals to verify the universality of our newly proposed 25deg gaze angle. Besides, in the previous publications, inverse relationships between the VOR gain and distance was claimed (12, 13). This increased gain was much lower than predicted calculation that indicated the limitation of VOR in vHIT. In clinics, the chair usually was set at 1m to 1.5m away from the target in a consideration of the vergence reflex and accommodations. However, a unified standard of this distance is still missing. In general, these experiments may help a new practice protocol to be introduced in the future.

Conclusion

Our experiments demonstrated the VOR gain reached peak around 25deg, which was contradict to the theoritical model and existing data. We proposed to set the target at the deflected angle while applied torsion at vertical semicircular canal planes. Besides, we test the new system that was able to perform vHIT that as good as long-standing vHIT systems, which indicated a vast potential for future developments and practices.

Data availability statements

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

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