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RESEARCH ARTICLE

Vestibulo-ocular reflex gain and compensatory saccades in three semicircular canals by video head impulse test

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Abstract

Background and Aim: One of the tools for assessing the vestibulo-ocular reflex (VOR) is using video head impulse test (vHIT). In this test by placing the head at different angles and shaking the head, three semicircular canals of the vestibular system in each ear can be examined separately. The purpose of this study was to investigate the relationship between the low and high velocities of the vHIT test with VOR and its compensatory saccades.

Methods: The vHIT test was performed by an examiner in 49 normal individuals aged 23–39 at low and high velocities. All participants had normal hearing, visual, and vestibular systems.

Results: Mean gains in the horizontal, anterior and posterior semicircular canals in the right ear respectively were 0.92, 1 and 0.90 and in the left ear 0.93, 0.99 and 0.95 for low velocity and 0.78, 0.92 and 0.79 in the right ear and 0.80, 0.85 and 0.86 in the left ear for high velocity. Also, the number of compensatory saccade at high velocity was higher than those at the low velocity and the latency of compensatory saccade was lower at the higher velocity.

Conclusion: In the vHIT test, VOR gain decreases at high velocity that is statistically significant. Also, compensatory saccades are more likely to occur at high velocity with smaller delay. Therefore, high-velocity vHIT test is not recommended for the purpose of examining the VOR gain and compensatory saccade.

Keywords: Video head impulse test; vestibulo-ocular reflex gain; compensatory saccade

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Introduction

The vestibular system is one of the body organs that in cooperation with the vision and proprioception, helps maintain body equilibrium [1]. One of the symptoms of vestibular system disorders is vertigo or dizziness. The prevalence of dizziness increases with age, reaching 30% at the age of 60 years and older, while in people over 80 years of age, the prevalence of this disorder increases up to 50%. It is also more common in women [2], but it is not related to race [3]. The semicircular canals are a part of vestibular system that respond to angular acceleration following head rotation. Currently, video head impulse test (vHIT) is used to examine the performance of semicircular canals by interpreting the results of vestibulo-ocular reflex

(VOR). VOR is a quick reflex that by creating compensatory eye movements in the opposite direction of the head rotation, helps maintain gaze and clear image of objects while moving the head or body. One of the characteristics of the VOR is the phase of the eye movement during head rotation, which specifies the VOR gain [4,5].

VOR gain is defined as the ratio of eye velocity to head velocity [6]. Various tests have been proposed to measure the VOR gain. One of these methods is the caloric test which was first introduced by Barany in 1914 [7] and used to test the performance of horizontal semicircular canals. Another method was presented by Hoshowsky et al. that calculated the VOR gain during head rotation by electrooculography (EOG) recording [8]. vHIT is another technique presented by Curthoys and Halmagyi [9] as a bedside test of VOR. In this test, the examiner quickly shakes the head of the subject as fast as daily head rotations, and at the same time eye movements are examined. vHIT allows to analyze eye and head movements and as a result calculate VOR.

vHIT is performed under passive and unpredictable head rotations in different directions to examine all three semicircular canals in both ears. In this test, the slow-phase response of eye movements is recorded during the head rotation, and then the VOR gain and latency, and the number of compensatory saccades are determined [10,11]. The mean VOR gain in this test has been reported as 1.06 ± 0.07. Normalized values of VOR gain in this test were assessed using Ulmer system by Wiener-Vacher and Wiener. They reported normalized values for horizontal, superior, and posterior semicircular canals as 1.02, 1.03, and 0.99, respectively [12].

Pathological results of vHIT in patients with impaired semicircular canal function is catch-up saccade which is a compensatory mechanism for recording eye movement in response to the rapid head rotation, in whom the VOR gain is also reduced [13]. Normal people can also create saccade, but abnormal saccades can be detected and assessed based on their velocity, range, and latency. Abnormal saccades are important sign of dysfunction in semicircular canals or afferent pathways [6].

With increasing age, the number and function of vestibular hair cells and nerve fibers reduce, which can be evaluated objectively by vHIT method and recording VOR gain. Regarding the greater loss of type I hair cells, VOR gain shows larger reduction in higher velocity impulses [14]. Finocchi et al. found out that VOR gain decreases with increasing age, and along with growth of smooth pursuit and optokinetic systems, help stabilize gaze and balance [15]. If the examiner immediately observes compensatory eye movements after rotating head, the VOR response is weak. Normal people can maintain their gaze on the target, but people with VOR deficits cannot maintain their gaze against rapid head rotation, and produce compensatory saccades while rotation toward the lesion [16].

By a brief review of the literature, it can be found that related studies have mostly focused on the horizontal semicircular canal so far and paid less attention on recording the VOR gain results in vertical semicircular canal. Those few studies conducted on vertical semicircular canal were confined to one velocity of head impulses. In addition, few studies have been carried out on the latency and the number of compensatory saccades in two different speed ranges of head rotations. Weber et al. and MacDougall et al. recommended that, in clinical tests, vHIT test be performed at high velocity. Head impulses at the velocity of less than 100°/s are not effective in detecting minor injuries in semicircular canals. The VOR gain values in many patients with unilateral vestibular disorder is within the normal range at low vHIT velocity, because they experience low velocity in everyday life allowing the compensation of procession [13,16]. Therefore, in clinical trials, vHIT should be performed at high velocity in order to detect semicircular canal injuries. This study aimed to examine the VOR gain and compensatory saccades in three semicircular canals using the vHIT test at low and high head velocities.

Methods

Forty-nine young adults aged 23–39 years

Table 1. Mean (standard deviation) of vestibule-ocular reflex gain in six semicircular directions at low and high head velocities

	Low velocity		High velocity	
Semicircular canal	**Right**	**Left**	**Right**	**Left**
Horizontal	0.92 (0.06)	0.93 (0.04)	0.78 (0.07)	0.80 (0.06)
Anterior	1.00 (0.02)	0.99 (0.05)	0.92 (0.07)	0.85 (0.05)
Posterior	0.90 (0.04)	0.95 (0.04)	0.79 (0.05)	0.86 (0.06)

(mean ± SD = 29.67 ± 4.89 years) participated in this study. None of the participants had vertigo, dizziness, and neurologic diseases associated with vestibular system, also no history of using specific medications that can affect the vestibular system. In addition, subjects had no spontaneous nystagmus with and without vision. For vHIT testing, the patient sat on a chair with his/her head at a suitable level for vertical and horizontal rotation by the examiner. The room light was dim in order to have appropriate recording. The patient was asked to stare at a target located at 2 m distance, while the vHIT device was placed between the target and the patient [17]. The examiner recorded vHIT using the Synapsys ® vHIT Ulmer system at high and low velocities of head rotations. To bring the semicircular canal into the horizontal plane, the patient tilted his/her head downward by 30°. The examiner was behind the patient and put his hands on the right position for quick head rotation. To perform vHIT at the right anterior and left posterior, the subject's head was moved about 35–45° to the left and head impulses were delivered up and down. To perform the test at the right posterior and right posterior, the subject's head was moved about 35–45° to the right and head impulses were delivered up and down. The head's rotations were random so the subject could not predict the direction of head movement. The number of head impulses at each direction was considered 20 [6]. The velocity of head rotations at two ranges of 100–250 and 250–400°/s was assessed. The effect of repeatability was examined at both low and high velocity.

The Synapsys ® vHIT Ulmer system calculated head movement based on the angle of head rotation [17] and its vHIT camera recorded head and eye movements. In maneuvers where the velocity of head rotation was not according to the mentioned rotation ranges, the system gives warning and that movement is not recorded in the results [12]. It should be noted that the head rotation angle was in a range of 5–15° [6].

After recording, the obtained data were analyzed in SPSS 24. Responses containing technical errors such as blinking or eyelid movements were removed from the data. To examine data distribution, the Kolmogorov-Smirnov test was performed and due to the normal data distribution, parametric tests were used. Paired t-test was used to evaluate the effect of different test velocities on VOR gain. To assess the effect of age on VOR gain, Pearson correlation test was carried out. Independent sample t-test was used to assess the effect of gender on the VOR gain and the latency of compensatory saccades.

Results

Mean (SD) VOR gain of 49 subjects in six anterior, posterior, and horizontal semicircular canal directions at low and high head velocities are presented in Table 1. All VOR gains decreased significantly at high head velocity ($p < 0.001$). Fig. 1 shows a sample of VOR recording at high head velocities. For horizontal semicircular canal, vHIT test velocity was 300°/s and 255°/s for anterior and posterior canals.

Compensatory saccades occurred in fewer

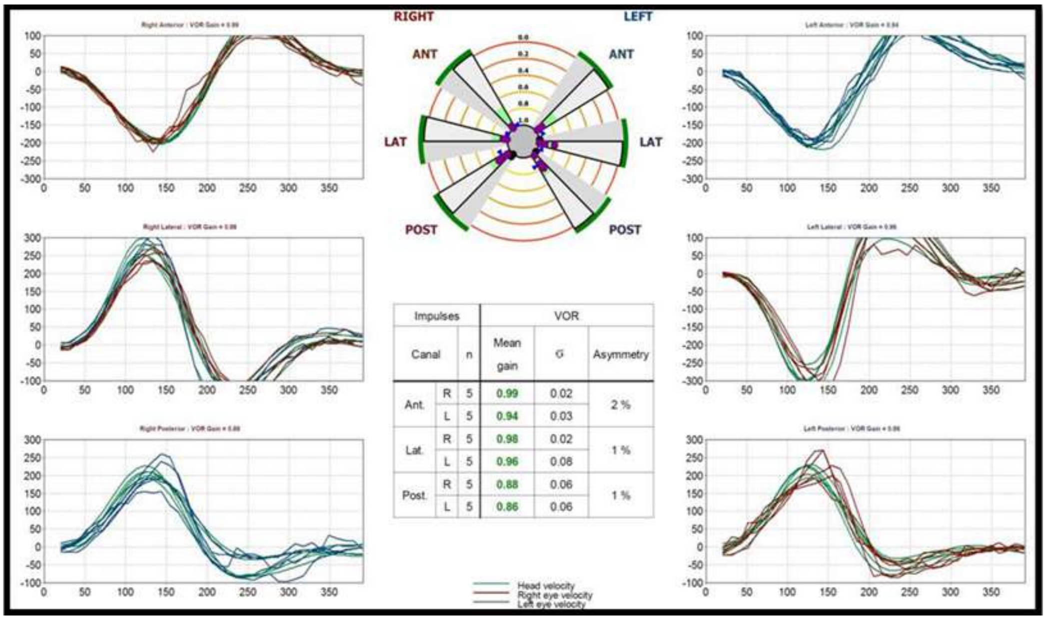

Fig. 1. A sample of vestibulo-ocular reflex recording in video head impulse test with high head velocity.

participants in low head velocity than in high velocity. The number of patients with compensatory saccades and their mean latency in three semicircular canals at high and low velocities are presented in Table 2.

There was no correlation between age and VOR gain (r = -0.104, p = 0.47). No significant relationship was found between VOR gain and gender (t = 1.052, df = 44.47, p = 0.29).

Discussion

This study examined the VOR gain and latency of compensatory saccades in three semicircular canals in both ears by using vHIT test at high and low velocities. With increasing head velocity, the mean VOR gain in all semicircles declined. In addition, by increasing velocity, the occurrence of compensatory saccades in all semicircular canals increased and their latency shortened. The average VOR gain in the horizontal, anterior, and posterior semicircular canals in the right ear were 0.92, 1.00 and 0.90, respectively. In the left ear, these values were 0.93, 0.95, and 0.99, respectively. In the study of Yang et al., the mean VOR gain for the horizontal canal of right and left ears were 1.03 and 1.01, respectively [18]. Naderi et al. reported the mean VOR gain for the horizontal and anterior semicircular canals as 0.96 and 0.93, respectively. Differences in the values of their study compared to ours may be due to the fluctuating nature of this response as well as different age groups in two studies [19].

In our study, at high head velocity, the mean VOR gain for horizontal, anterior, and posterior canals were obtained as 0.78, 0.92, and 0.79 in the right ear, and 0.80, 0.85, and 0.86 in the left ear, respectively. These results indicate that, with increasing head velocity, the VOR gain significantly decreases ($p < 0.05$). As previously noted, mean VOR gain had reduced with respect to low velocity in all semicircular canals and Matiño-Soler et al. results supports our study results [20]. According to MacDougall et al., the minimum normal VOR gain is 0.68. This low value makes diagnosis difficult as this low reduction might be due to aging or vestibular pathology [16]. Since the purpose of VOR system is to maintain gaze stability in the retina for everyday activities, it can be argued that the VOR reflex has the highest efficiency in low head velocities which is appropriate for everyday activities. In addition, in normal young adults, there is a significant number of receptors in

Table 2. Occurrence and latency of compensatory saccades in low and high head velocities

		Occurrence (N.)		Mean latency (SD)	
	Semicircular canal	**Low velocity**	**High velocity**	**Low velocity**	**High velocity**
Left ear	**Horizontal**	10	42	91.70 (6.75)	99.12 (11.51)
	Anterior	-	11	-	107.55 (9.08)
	Posterior	8	40	123.00 (6.84)	106.05 (21.76)
Right ear	**Horizontal**	6	32	108.33 (14.93)	117.16 (20.43)
	Anterior	-	-	-	-
	Posterior	9	37	145.00 (21.96)	112.05 (14.90)

each semicircular canals, which decreases with increasing age. So, why many adults with a significant reduction in the receptor number have normal performance? The answer may be, the vestibular system can work well in spite of decrease in its sensory cells and nerve fibers, and accumulation of waste materials inside epithelial cells [21].

In the current study, the number of compensatory saccades increased at high head velocities and their latency shortened. In our study period, age had no significant effect on the number of compensatory saccades and their latency. We observed that patients with low VOR gain had shorter saccade latency, but Matiño-Soler et al. suggested that the effect of increasing age be considered on the occurrence of compensatory saccades in older people [20]. Anson et al. reported that the elderly people had higher compensatory saccades than young people, and there was no significant difference between them in terms of saccade latency [22]. Naderi et al. found out that compensatory saccades existed in 13.6% of subjects younger than 50 years and in 50% in people older than 50 years [19]. Yang et al. examined 50 normal subjects and observed that compensatory saccades occurred in 22.6% of the impulses and in 49% of the ears, and concluded that the occurrence of compensatory saccades was not related to the age which is consistent with our results [18]. Due to reduced VOR gain, head impulses to one side causes the gaze instability on the target, or the so called retinal slip, which results in the position error message transmitted to higher centers, during which compensatory saccades are created [23].

In our study, we found out that gender had no significant effect on the VOR gain ($p > 0.05$). This is in agreement with the findings of Wall et al. [24] and Matiño-Soler et al. [20].

In our study, age also had no significant effect on VOR gain ($p > 0.05$). McGarvie et al. in their study showed that the VOR gain in young people was close to 1, which slightly decreased with increasing age [25]. The decline in recorded VOR was also observed in vertical semicircular canals. Also, there was no significant difference in the amount of VOR gain reduction in horizontal and vertical semicircular canals [25]. Results of Maheu et al. [26] indicate that the VOR gain in the semicircular canals decreases as age increases. This decrease was higher in tests with higher velocities. Their results also indicate that the mean VOR gain in the horizontal semicircular canal is between 0.8 and 1.2, and for each 10 years of age increase, the mean gain decreases about 0.012 [26]. Mossman et al. examined the VOR gain at different ages, and their results indicated a decline in gain at higher ages [27]. Perhaps the reason for the lack of effect of age factor in the present study is the age limit of our study participants.

Conclusion

In vHIT, the VOR gain at high head velocities was significantly lower than that conducted at low velocities. In addition, compensatory saccades were more likely to occur at high head velocities with shorter latency.

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Conflict of interest

The authors declare that they have no conflict of interest.

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