



Corrective Saccades in Unilateral and Bilateral Vestibular Hypofunction During Slow Rotation Expressed by Visually Enhanced VOR and VOR Suppression: Role of the Cerebellum

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Abstract

In clinical practice, the head impulse test paradigm (HIMP) and the suppression head impulse paradigm (SHIMP) stimulate high-frequency head movements so that the visual system is temporarily suppressed. The two tests could also be useful tools for vestibular assessment at low frequencies: VVOR (visually enhanced vestibulo-ocular reflex) and VORS (vestibulo-ocular reflex suppression). The aim of this study is to analyze the eye movements typically found during VVOR and VORS testing in patients with unilateral and bilateral vestibular hypofunction. Twenty patients with unilateral vestibular hypofunction, three patients with bilateral vestibular hypofunction, and ten patients with normal vestibular function (control group) were analyzed through VVOR and VORS testing with an Otometrics ICS Impulse system. During the VVOR test, patients with unilateral vestibular hypofunction exhibited corrective saccades to the same direction of the nystagmus fast phase toward the healthy side when the head rotates toward the affected side, while patients with bilateral vestibular hypofunction exhibited corrective saccades to the opposite side of head movements to each side. During the VORS test, patients with unilateral vestibular hypofunction seem to exhibit larger corrective saccades to the healthy side when the head was moved to this side, while patients with bilateral vestibular hypofunction did not exhibit corrective saccades during head movements to either side. Our data suggest that the VVOR and VORS tests yield the same diagnostic information as the HIMP and SHIMP tests in unilateral and bilateral vestibular hypofunction, and can contribute to the diagnosis of a peripheral vestibular loss as well as the affected side.

Keywords Vestibulo-ocular reflex · Eye movements · Head movements · Vestibular function tests · Vestibular disorders

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Introduction

Different classes of eye movements can be distinguished on the basis of how they aid vision, their physiological properties, and their anatomical substrate. Clear vision requires that images of our environment during head movements be held stable on the retina. This is made possible by several functional classes of human eye movements, such as smooth pursuit (SP), optokinetic (OKN), and the vestibulo-ocular reflex (VOR) [1].

It is possible to suppress a particular stimulus for a specific purpose (goal planning/goal in mind). The flocculus and paraflocculus generate the smooth pursuit and modulate the neural integrator responsible for the excentric gaze. The smooth pursuit reflex comprises an eye movement in order to stabilize the image of a moving target on the fovea. The ability of the pursuit reflex to overcome an inappropriate VOR, known as VOR suppression, is indispensable during combined eye-head tracking of a target that moves in the same direction as the head; otherwise, the VOR would move the eye in the opposite direction [2, 3]. In addition, there is no

difference between the eye movement of a pursuit reflex with and without head movement while staring at a fixed target [1].

The sensitivity of the visual and vestibular system to detect head movements depends on frequency. The visual system is more effective at low-frequency head movements; conversely, the semicircular canals are more sensitive to high-frequency head movements [4].

In clinical practice, tests such as the head impulse test paradigm (HIMP) and the suppression head impulse paradigm (SHIMP) stimulate high-acceleration head movements so that the visual system is temporarily suppressed. In low frequencies, two additional tests could be useful tools for vestibular assessment: the visually enhanced vestibulo-ocular reflex (VVOR) and the vestibulo-ocular reflex suppression (VORS). The HIMP and VVOR are almost identical, with both involving a fixed target and a head movement. The SHIMP and VORS are similar tests, as they both involve head movements to track a moving target. However, while HIMP and SHIMP are not influenced by the visual system, in the VVOR and VORS tests, vision predominates over the vestibular system.

The aim of this study is to investigate the eye movements typically found during VVOR and VORS testing in patients with unilateral and bilateral vestibular hypofunction.

Materials and Methods

This is a prospective study conducted in accordance with the Declaration of Helsinki and approved by the Research Ethics Committee of Brazilian Lutheran University (ULBRA RS) in Canoas (CAEE 06137012.3.2002.5349). All subjects participated voluntarily and informed consent was obtained from all individual participants included in the study.

The sample consisted of twenty patients (twelve female) with unilateral vestibular hypofunction (UVH), three patients (two female) with bilateral vestibular hypofunction, and ten patients (five female) with normal vestibular function, serving as controls. Patients were submitted to an ocular motor examination with video-frenzel system including evaluation of spontaneous and gaze-evoked nystagmus, smooth pursuit, saccades, cover test, clinical head impulse test, head shaking test, and head shaking tilt suppression test in addition to routine neurologic examination. The HIMP, SHIMP, VVOR, and VORS findings of all participants were obtained using an Otometrics ICS Impulse system. Patients with vestibular hypofunction were diagnosed on the basis of reduced VOR gain on video head impulse test affecting both the anterior and lateral semicircular canals or all semicircular canals in the affected ear or in both ears. VOR gain was considered reduced if less than 0.8 in the lateral semicircular canals and less than 0.7 in the vertical semicircular canals.

For the VVOR test, subjects were asked to stare at a fixed dot on the wall at a distance of 1.5 m. Their heads were slowly moved at the same frequency and amplitude (about 0.5 Hz and 10° in the horizontal plane), but patients were asked to keep their eyes fixed on the stationary dot during the test.

For the VORS test, subjects were tested in sitting position and asked to stare at a laser dot on the wall at a distance of 1.5 m. Their heads were slowly moved at a frequency of approximately 0.5 Hz and amplitude of 10° in the horizontal plane, while the laser dot moved with the patient's head. Patients were asked to follow the moving laser dot during the test.

Results

The age of the patients ranged from 20 to 75 years. Reduced VOR gain in the lateral and anterior left semicircular canals was observed in eight patients; in the lateral and anterior right semicircular canals six patients; in the lateral, anterior, and posterior left semicircular canals in four patients; in the lateral, anterior, and posterior right semicircular canals in two patients; and in the lateral, anterior, and posterior semicircular canals bilaterally in three patients. The VOR gain of the lateral semicircular canal in the HIMP of the healthy patients ranged from 0.9 to 1.13, in the patients with unilateral vestibular hypofunction ranged from 0.17 to 0.55, and in the patients with bilateral vestibular hypofunction ranged from 0.01 to 0.09.

Patients with unilateral vestibular hypofunction showed horizontal spontaneous nystagmus toward the nonaffected ear, gaze-evoked nystagmus following the Alexander's Law, pathologic clinical head impulse test when performed toward the affected ear, apparent horizontal saccadic pursuit (secondary to the spontaneous nystagmus) [5], normal saccades, head shaking test enhancing the spontaneous nystagmus intensity, and suppressed after head tilting [6]. These findings confirmed the diagnosis of vestibular neuritis and the neurologic examination did not detect any focal deficit. Patients with bilateral vestibular hypofunction had no confirmed etiology and no pathologic findings in the ocular motor and neurologic examination. Brain MRI was performed and no intracranial lesion was found.

All patients with unilateral hypofunction were tested during the first 5 days after onset of vestibular symptoms. All patients with bilateral hypofunction were tested at least 3 months after onset of vestibular symptoms.

During the VVOR test, patients with unilateral vestibular hypofunction exhibited corrective saccades to the same direction of the nystagmus fast phase toward the healthy side when the head rotates toward the affected

side. Patients with bilateral vestibular hypofunction exhibited corrective saccades to the opposite side of the head movement to both sides (Fig. 1).

In the VORS test, patients with unilateral vestibular hypofunction seemed to exhibit larger correctives saccades to the healthy side when the head was moved to this side, while patients with bilateral vestibular hypofunction did not show any corrective saccades during head movement to either side (Fig. 2).

Discussion

Our data suggest that VVOR and VORS tests exhibited the same findings as the HIMP and SHIMP in unilateral and bilateral vestibular hypofunction, and can contribute to the diagnosis of a peripheral vestibular loss as well as the affected side.

The flocculus of the cerebellum plays a role adjusting the gain of the rotational VOR during the head movement. Patients with vestibular loss, who have an abnormal gain of the rotational VOR, may show corrective saccades during sinusoidal head rotation during attempted fixation upon a target even when the visual tracking systems are normal. These saccades will be directed opposite to the movement of the head when the gain is too low. On the other hand, saccades will be directed in the same direction of the head movement when the gain is too high [1].

In the acute phase of an UVH, there is an imbalance between the vestibular afferences from the left and right sides. In an UVH affecting the left side, the brain interprets that the head is rotating to the right; hence, the eyes move slowly to the affected left side (slow phase of spontaneous nystagmus). To stabilize the image on the retina, the brain quickly moves the eyes to the healthy right side (fast phase of spontaneous nystagmus) [2].

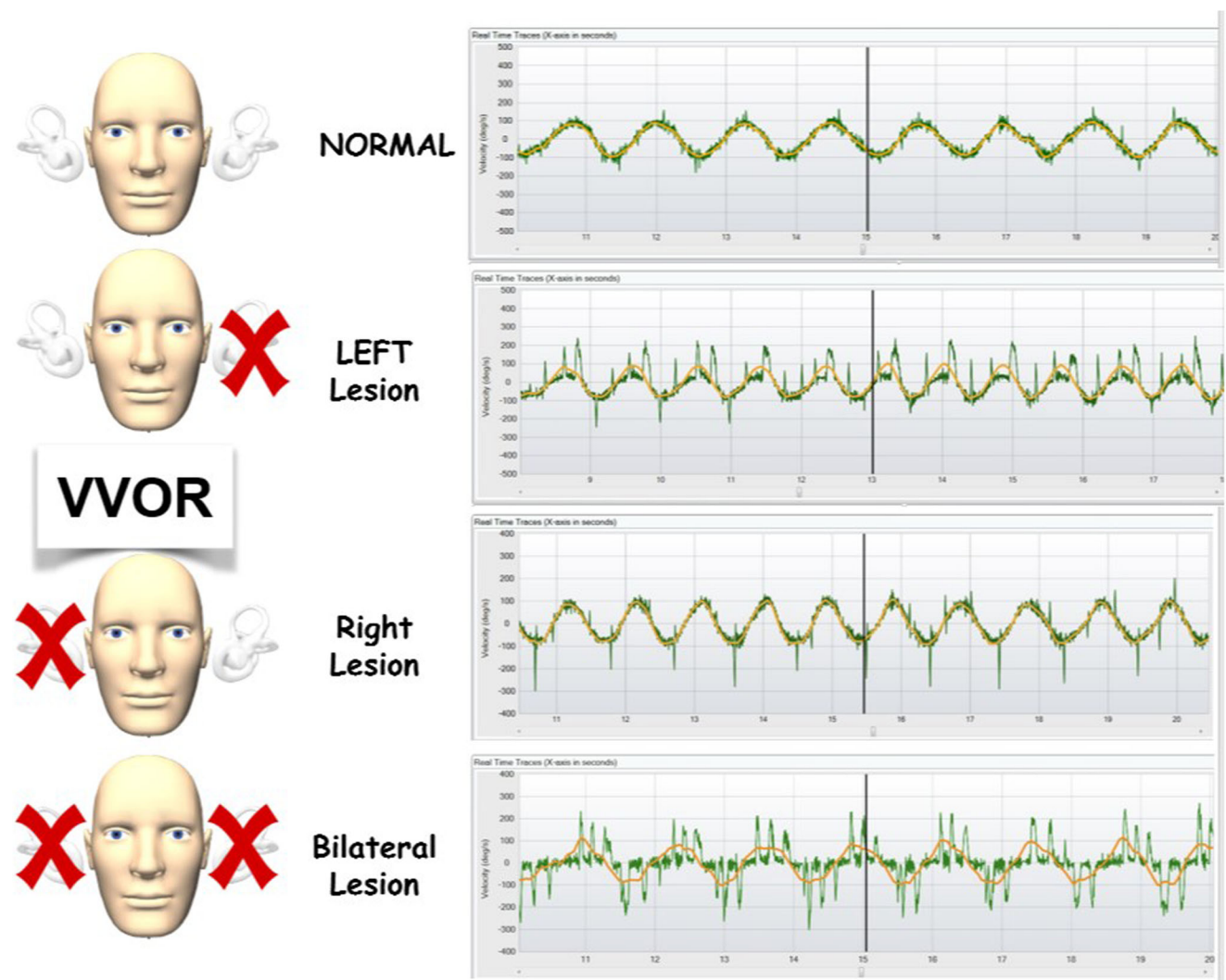


Fig. 1 VVOR test (head moving and target fixed) results in controls, patients with unilateral vestibular hypofunction affecting the right and left sides, and patients with bilateral vestibular hypofunction



Fig. 2 VORS test (target and head moving) results in controls, patients with unilateral vestibular hypofunction affecting the right and left sides, and patients with bilateral vestibular hypofunction

In UVH, the HIMP shows reduced VOR gain followed by catch-up saccades when the head is turned to the affected side. On the other hand, SHIMP demonstrates refixation saccades when the head is turned to the unaffected side, and smaller saccades when the head is turned to the affected side [7–9].

The VVOR test assesses the patient's VOR with visual enhancement. Unlike the HIMP, it evaluates low-frequency head movements, which means that the pursuit reflex acts together with the VOR to move the eyes contralaterally to the head movement [10]. For instance, in an UVH affecting the left side, there is reduced VOR gain when the head is turned to this side. In the VVOR test, when the head is turned to the right side, both the pursuit and vestibulo-ocular reflexes are intact, so that there is no abnormal eye movement. On the other hand, the VOR does not move the eyes to the right when the head is turned to the left. Hence, a corrective saccade to the right is needed during the head movement to keep the target on the fovea, along with the pursuit reflex [1, 2].

Rey-Martinez et al. [11] developed mathematical methods for measuring the VVOR gain in healthy patients, unilateral vestibular hypofunction with vestibular neurectomy, bilateral vestibulopathy, and CANVAS. The patients with UVH were submitted to a previous neurectomy and were not tested in the acute phase, which differs from our study. Hence, the mean objective was not focused on the saccadic analysis. On the other hand, we have focused on the description of corrective saccades findings during this test.

During the VVOR test performed in a patient with bilateral vestibular hypofunction, the VOR does not move the eyes to the side opposite to head movement. Therefore, a corrective saccade beating contralaterally to the head movement for both sides is needed to keep the eyes on the stationary target. These findings in bilateral lesions, which occur due to poor VOR gain, coupled with bilateral positive head impulse test and poor dynamic visual acuity may provide greater clinical confidence on the diagnosis of bilateral vestibulopathy.

The VORS test assesses the patient's VOR during visual suppression. Differently from the SHIMP and like the VVOR, it evaluates low-frequency head movements, which means that the pursuit reflex moves the eyes in the same direction as the target, while the VOR tends to move the eyes to the opposite direction [10]. Therefore, corrective saccades are needed to keep the target on the fovea in healthy patients. In an UVH affecting the left side, there is reduced VOR gain when the head is turned to this side. In the VORS test, the abnormal VOR gain does not move the eye completely to the right when the head is turned to the left; hence, there is a minor VOR suppression, while the pursuit reflex moves the eyes to the left, following the target. On the other hand, when the head is turned to the right, the VOR moves the eyes back to the left. Hence, a corrective saccade to the right side is needed to overcome the inappropriate VOR (VOR suppression) [1–3]. As a result, these patients seem to exhibit larger corrective saccades to the healthy side when the head is moved to this side.

In the VORS test performed in a patient with bilateral vestibular hypofunction, the reduced VOR gain does not move the eye to the opposite side of the head movement. Therefore, there is no corrective saccade during head movement to either side, since there is no need to suppress the VOR.

The small number of patients in our series could be considered a limitation. However, this was a descriptive study that showed similar findings in different groups; we believe that a larger sample would not have changed our results.

VVOR and VORS testing could add to the usual video head impulse test protocol by demonstrating the interaction between the lesioned peripheral vestibular system and the adaptive process of the central nervous system. Both tests are vision dependent and probably play a major role in vestibular adaptation (in peripheral and probably central vestibular lesions) [12]. Substitution by another type of eye movement system can effectively cancel the vestibular deficit and decrease the retinal slip during head movements [13]. At this point, corrective saccades become a part of the adaptive strategy to augment the diminished slow-phase component of the VOR for vestibular rehabilitation [14].

In conclusion, the VVOR and VORS yield similar diagnostic information than the HIMP and SHIMP respectively, just examining different frequencies and exhibiting very similar findings in unilateral and bilateral vestibular hypofunction.

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Compliance with Ethical Standards This is a prospective study conducted in accordance with the Declaration of Helsinki and approved by the Research Ethics Committee of Brazilian Lutheran University (ULBRA RS) in Canoas (CAEE 06137012.3.2002.5349). All subjects participated voluntarily and informed consent was obtained from all individual participants included in the study.

Conflict of Interest The authors declare that there is no conflict of interest.

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