

VESTIBOLOGY

Vertical saccades during horizontal head impulses: a sign of posterior semicircular canal hypofunction

Francesco d'Onofrio¹, Letizia Neri², Giampiero Neri¹

¹ Department of Neurosciences, Imaging, and Clinical Sciences, University of Chieti-Pescara, Chieti, Italy; ² Department of Otorhinolaryngology, University of Insubria and ASST Sette Laghi, Varese, Italy

SUMMARY

Objective. We describe an uncharacteristic vestibular-ocular reflex (VOR) pattern, studied by video head impulse tests (VHIT) in patients suffering from unilateral isolated posterior semicircular canal (PSC) hypofunction. In these patients, we found an upward sliding of the eyes, followed by an oblique downward catch-up saccade during horizontal head impulse to the healthy side.

Methods. We present a retrospective study of all VHIT exams presenting isolated PSC hypofunction between May 2020 and November 2022.

Results. We found 37 patients, which led to the discovery of such incongruent eye movement in 19 cases; their gain data are shown and compared to the remaining 18 cases in which such an anomaly was absent. A control group of 31 healthy subjects was recruited to define the reference criteria for VHIT gain values. The correlation between the amplitude of the vertical saccade and the relative functional imbalance of the vertical semicircular canals was studied.

Conclusions. We have observed that in approximately half of the subjects with isolated CSP deficiency, there is a VOR anomaly. A possible pathophysiological explanation of the unbalanced effect of vertical semicircular canal stimulation of a labyrinth during horizontal head thrust toward the opposite side is proposed. The planar incongruity of the response of the VOR described here appears more evident at the onset of the CSP deficit. Current VHIT systems do not detect this incongruent eye reflex. They can lead to an error in gain evaluation (pseudo-deficit) of the lateral semicircular canal of the healthy side and problems in performing the test (trace rejected). In the future, software for VHIT should take into account the possibility of non-coplanar ocular responses to cephalic stimuli.

KEY WORDS: video head impulse test (VHIT), posterior semicircular canal hypofunction, vestibular-ocular reflex (VOR) anomalies, vertical catch-up saccade

Introduction

The video head impulse test (VHIT) analyses the function of each semicircular canal, allowing a very accurate assessment of eye movements due to the vestibular-ocular reflex (VOR) during head impulses. In many patients with unilateral isolated hypofunction of the posterior semicircular canal (PSC), we found an abnormal eye movement at the horizontal impulse of the head towards the healthy side, consisting of the upward sliding of the eyes during the movement of the head, followed by a downward saccade after the head stops.

A retrospective evaluation of our VHIT database was carried out for these VOR planar incongruities. All VHIT gain data from these cases were collected to correlate the presence and amplitude of the downward saccades to the gain values of both vertical canals of the hypofunctional side. A slow-motion video analysis of these abnormal eye movements during and after head impulse is shown in Figures 1 and 2.

A possible pathophysiological explanation is proposed consisting of the unbalanced effect of stimulating both ipsilateral vertical semicircular canals

Received: February 2, 2023

Accepted: October 16, 2023

Published online: May 3, 2024

Correspondence

Giampiero Neri

E-mail: giampiero.neri@unich.it

How to cite this article: d'Onofrio F, Neri L, Neri G. Vertical saccades during horizontal head impulses: a sign of posterior semicircular canal hypofunction. *Acta Otorhinolaryngol Ital* 2024;44:198-203. <https://doi.org/10.14639/0392-100X-N2508>

© Società Italiana di Otorinolaringoiatria e Chirurgia Cervico-Facciale



OPEN ACCESS

This is an open access article distributed in accordance with the CC-BY-NC-ND (Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International) license. The article can be used by giving appropriate credit and mentioning the license, but only for non-commercial purposes and only in the original version. For further information: <https://creativecommons.org/licenses/by-nc-nd/4.0/deed.en>

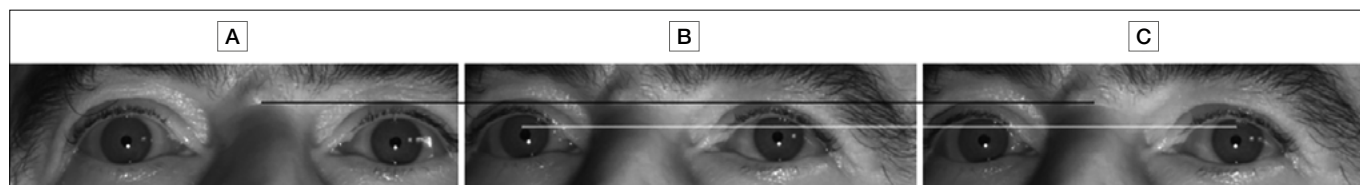


Figure 1. Slow motion video analysis of eye movement during horizontal head impulse toward the healthy side: at the beginning of the head impulse (A), just before the catch-up saccade (B) and after it (C). The black line on face marks is used for proper alignment of pictures. The white line indicates the starting position of the pupils just before the saccade.

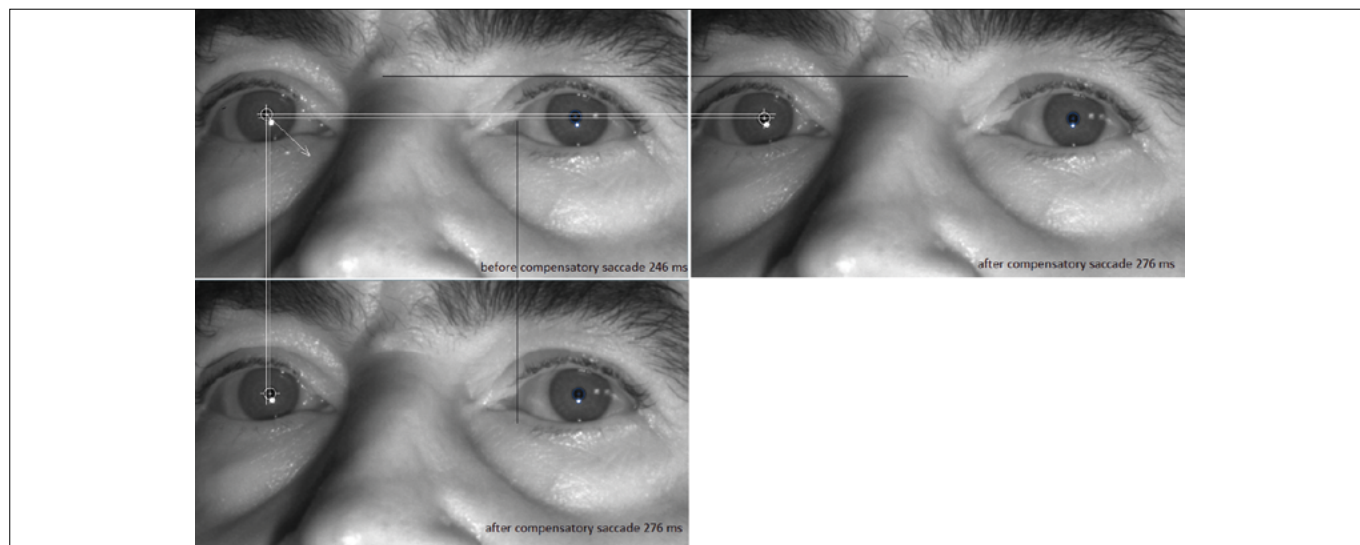


Figure 2. Slow motion video analysis of the catch-up saccade after horizontal head impulse toward the healthy side. Black lines: references on facial marks for image alignment. White lines: right eye position before the compensatory saccade. Grey lines: right eye position after the catch-up saccade. The white arrow on the right eye shows the direction of the saccade, which is mainly vertical downward, with a horizontal component to the left.

(SCs) of a labyrinth during the horizontal thrust of the head towards the opposite side. To our knowledge, we have not found previous descriptions in the literature of perverted downward catch-up saccades following horizontal head impulses in peripheral vestibulopathy.

Materials and methods

A retrospective study of all VHIT examinations performed from May 2020 to November 2022 was carried out, looking for patients with unilateral PSC hypofunction. All patients underwent VHIT on each plane of the SCs using the Synapsys VHIT system (Inventis SRL, Padua, Italy); with this device, a gain value of more than 0.85 for horizontal SC and 0.75 for vertical SC is considered normal. To exclude central vestibular diseases, all the patients were examined under Frenzel's glasses for spontaneous and positional nystagmus (ny) in sitting, supine, head hanging position, left and right side lying and after diagnostic manoeuvres according to Dix

and Hallpike, gaze and rebound ny were also sought; they also underwent Unterberger Test and Head Shaking Test. Patients with a history of neurological disorders were excluded. Patients were examined on an outpatient basis, and no central nervous system imaging was routinely ordered. Further investigations were carried out for patients who complained of symptoms at control visits.

All patients gave their authorisation to use their data and video recordings for scientific purposes. All VHIT video recordings of patients presenting unilateral PSC hypofunction were re-examined to find VOR planar incongruences during horizontal impulses. The video sequences of eye movements were analysed in slow motion, and the amplitude of vertical saccades found was reported as small (< 2 angular degrees) or large (> 2 angular degrees). The PSC gain was correlated with that of the ipsilateral anterior semicircular canal (ASC) and with the corresponding vertical amplitude of the saccade. A control group of healthy subjects was recruited to define the reference criteria for VHIT gain values.

Table I. Group A. For each patient, gender, age, gain values of homolateral PSC and ASC, the absolute difference (ASC-PSC), the relative difference (100XAD/ASC), the amplitude of the downward catch-up saccade and the diagnosis are reported.

N	Gender	Age	Group A				Amplitude	Diagnosis
			PSC	ASC	AD	RD		
1	M	64	0.55	0.86	0.31	36	Large	BPPV
2	F	61	0.42	1.08	0.66	61.1	Large	BPPV
3	F	50	0.4	0.95	0.55	57.9	Large	BPPV
4	F	74	0.55	1.04	0.49	47.1	Large	U
5	M	66	0.03	1.08	1.05	97.2	Large	CJ
6	F	75	0.56	0.93	0.37	39.8	Large	BPPV
7	M	67	0.08	1.1	1.02	92.7	Large	U
8	F	65	0.69	1.03	0.34	33	Large	BPPV
9	M	80	0.36	0.93	0.57	61.3	Large	BPPV
10	M	78	0.58	1.06	0.48	45.3	Large	BPPV
11	M	82	0.6	1.02	0.42	41.2	Large	U
12	M	73	0.65	0.88	0.23	26.1	Large	BPPV
13	F	54	0.84	1.02	0.18	17.6	Large	BPPV
14	M	64	0.66	0.95	0.29	30.5	Small	BPPV
15	F	53	0.76	1.09	0.33	30.3	Small	U
16	F	57	0.64	0.95	0.31	32.6	Small	BPPV
17	F	69	0.55	0.9	0.35	38.9	Small	BPPV
18	F	47	0.31	1.11	0.8	72.1	Small	U
19	F	45	0.62	0.86	0.24	27.9	Small	BPPV

PSC: posterior semicircular canal; ASC: anterior semicircular canal; AD: absolute difference; RD: relative difference; BPPV: benign paroxysmal positional vertigo, CJ: canalith jam, U: unknown.

Table II. Group B. For each patient, gender, age, gain values of homolateral PSC and ASC, the absolute difference (ASC-PSC), the relative difference (100XAD/ASC) and the diagnosis are reported.

N	Gender	Age	Group B				Diagnosis
			PSC	ASC	AD	RD	
1	F	60	0.65	1	0.35	35	BPPV
2	M	73	0.59	0.95	0.36	37.9	U
3	F	72	0.58	0.96	0.38	39.6	BPPV
4	F	82	0.58	0.96	0.38	39.6	BPPV
5	F	66	0.65	0.98	0.33	33.7	BPPV
6	F	38	0.64	1.01	0.37	36.6	BPPV
7	F	62	0.68	1.07	0.39	36.4	BPPV
8	M	52	0.6	0.77	0.17	22.1	U
9	M	82	0.69	0.94	0.25	26.6	BPPV
10	F	46	0.59	0.93	0.34	36.6	BPPV
11	M	37	0.68	1.03	0.35	34	U
12	M	38	0.68	0.8	0.12	15	BPPV
13	M	60	0.61	1.13	0.52	46	BPPV
14	F	23	0.43	1	0.57	57	BPPV
15	F	65	0.54	0.92	0.38	41.3	BPPV
16	F	68	0.66	0.98	0.32	32.7	BPPV
17	F	48	0.57	1	0.43	43	BPPV
18	M	58	0.68	1.05	0.37	35.2	BPPV

PSC: posterior semicircular canal; ASC: anterior semicircular canal; AD: absolute difference; RD: relative difference; BPPV: benign paroxysmal positional vertigo, U: unknown.

Results

In 2.5 years of activity, we observed 37 cases of isolated unilateral PSC hypofunction. In 19 cases (group A), we found this peculiar eye movement during the horizontal head impulse toward the healthy side: 8 patients were males, 11 were females, with ages between 45 and 82 years; 12 were referrals from the Emergency Department.

In all, 18 patients (group B) with isolated unilateral PSC hypofunction did not show abnormal eye movement: 7 males and 11 females, aged between 23 and 82 years; 4 were referrals from the Emergency Department. In the same period, 31 healthy subjects (18 females and 13 males) aged between 29 and 76 years were recruited as a control group.

Characteristics of patients in groups A and B are listed in Tables I and II, respectively, which report the gain values for homolateral PSC and ASC and their difference (ASC-PSC), indicated as absolute delta (AD), as well as the same difference expressed in percentage on ASC function (100XAD/ASC), denoted as relative delta (RD), the amplitude of the vertical saccade and the diagnosis.

We identified the RD as the numeric expression of the unbalanced action of the vertical canals during contralateral impulsive head rotation.

The control group consisted of 27 cases in whom the CSA had a more significant gain than the CSP, and the average RD value was 10.17% with confidence limits (i.e., the average value minus/plus one standard deviation) of 5-15.2%.

In the remaining 4 cases, the gain of the CSP was more significant than the CSA (mean RD value -7.03%). We considered an RD value of 15% as the cut-off for normality.

In group A, the overall mean RD was 47% (min. 18%, max. 97%), and the confidence limits were 25% and 69%. In group B, the overall mean RD was 36% (min. 15%, max.

57%), and the lower and upper confidence limits were 27% and 45%, respectively.

In Figure 3, RD values are divided into increasing steps for both groups (A and B); cases with small amplitude saccades are highlighted, and the normal range is shown (control group). Most patients in group B are assembled in the 30-40% range, while in group A, they are widely spread across all ranges of RD values. The two groups overlap in the range of 10-50% RD; no case in group B had an RD higher than 60%. All but one case presenting small oblique saccades were found with an RD less than 40%.

Discussion

Vertical eye movements during horizontal head impulses have been described in central vestibular diseases (cerebellar pathologies and Chiari malformation) due to loss of inhibition of the ASC input when it is excited during yaw thrusts^{1,2}. Regarding peripheral vestibulopathy, an incongruent vertical upward catch-up saccade³ after horizontal head impulses has been reported in superior vestibular neuritis due to the prevalence of PSC function⁴. Most pitfalls⁵ due to technical errors, presence of blinks, the degree of tightness of the goggle strap and neck resistance to passive movements, or intrusive eye movement disorders may interfere with the interpretation of VHIT data^{6,7}. According to a study from the Baltimore school, the effect of a cephalic impulse on the horizontal plane is not expressed exclusively on the lateral SCs (LSCs) but also on the vertical SCs. It has been estimated that the kinetic energy impressed with the horizontal cephalic impulse stimulates all canals with different efficiency: 94% for the LSC, 18% for the ASC and 26% for the PSC⁸.

This stimulation is caused by a vertical canal inclination of about 45° with respect to the sagittal plane. Utriculipetal currents stimulate the LSC, while the PSC and ASC are excited by utriculifugal currents. It thus follows that a horizontal impulse to the right maximally excites the right LSC and partially the left PSC and ASC. The effect of this “associated” stimulation of vertical SC is negligible during slow head movements but becomes significant during head thrusts. In a subject with normal bilateral labyrinthine function, during horizontal thrusts, the simultaneous action of the two homolateral vertical SCs involves a mutual annihilation of the vertical components (of opposite direction), with active stabilisation of the gaze on the horizontal plane, and only the action of LSC moves the eyes.

In case of an isolated PSC deficit, during a rotation of the head towards the healthy side, the eyes rotate in the horizontal plane due to the action of LSC of the healthy side; however, due to the action of ASC of the impaired side, they improperly move upward as well (Fig. 4). The selective hypofunction of only

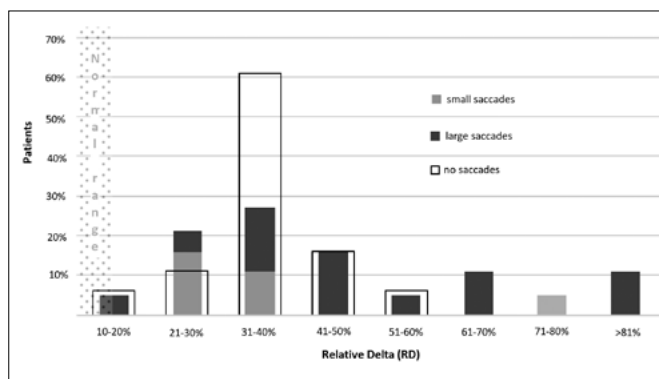


Figure 3. Patients, in percentage, divided into increasing RD steps: dark grey for patients with large saccades, light grey for small saccades and white for group B (no saccades). The grey dotted band indicates the normal RD range (control group).

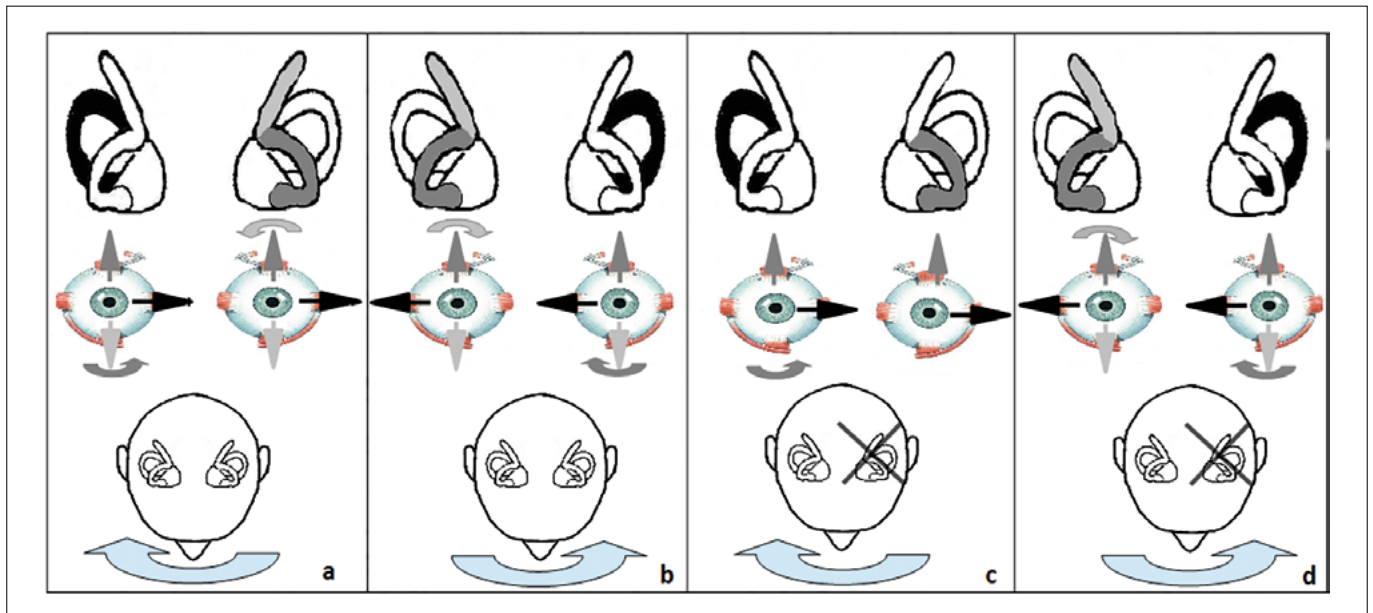


Figure 4. Activation of SCs and their effects on eye movements during horizontal head impulse in normal conditions (**A** and **B**) and left PSC isolated hypofunction (**C** and **D**). Activated SCs are highlighted (LSC: black, ASC: dark grey, PSC: light grey). Black arrows: effects of LSC activation; dark grey arrows: effects of ASC activation; light grey arrows: effects of PSC activation. In normal conditions (**A** and **B**), activation of both vertical SCs stabilises the eyes in the vertical plane; only the action of LSC moves them. In case of an isolated left PSC deficit, during rotation of the head towards the healthy side (**C**), the eyes rotate in the horizontal plane due to the action of right LSC; however, due to the action of left ASC alone, they improperly move upward as well. During the impulse of the head towards the affected side (**D**), the eyes move as in normal condition.

one vertical SC of labyrinth results in a planar incongruence of the VOR in response to horizontal cephalic impulses performed towards the healthy side, due to a stimulation of the functioning vertical SC that is not counterbalanced by the impaired homolateral SC, with the appearance of a vertical component that will go upward in isolated PSC deficits, as in our cases, or downwards in ASC deficits, as previously described in superior vestibular neuritis.

The incongruent VOR seems most evident in the early stage of onset of PSC hypofunction, as most of the patients in group A (12/19) came from the Emergency Department. In contrast, only a few in group B were seen in emergency (4/18). The presence and amplitude of vertical eye movements tend to be proportional to RD values: RD above 60% certainly elicits vertical saccades; small saccades are mostly present for RD lesser than 40%. Further studies are necessary to evaluate the temporal evolution of this clinical sign and its relation to specific pathologies ⁹.

The algorithms used in the current quantitative gain analysis of VHIT devices do not consider the planar incongruence of the VOR described herein; they only evaluate the extent of eye movement without indicating its direction. Vertical saccades are usually clearly visible on healthy LSC VHIT velocity traces but are not highlighted as perverse responses by automatic analysis (Fig. 5).

It often happens that the vertical eye responses are discarded by default (with difficulty in performing the test) or, when accepted, an error in evaluating the LSC gain can occur. The perverted eye response reduces the horizontal VOR gain, but this is not due to LSC dysfunction (pseudo-deficit). Due to the limits of VHIT systems mentioned above, we recommend personally examining the video recordings of eye movements during horizontal head impulses when an isolated vertical canal hypofunction is found at VHIT.

Conclusions

The selective hypofunction of a PSC causes an upward shift of the eyes during a horizontal cephalic impulse directed towards the healthy side, followed by an oblique downward catch-up saccade. Usually the oblique saccades can be easily identified in the VHIT velocity trace of the LSC opposite to the impaired PSC. Vertical saccades seem to be clearly visible in the early stage of the disease. The amplitude of eye movement tends to be proportional to the difference in function between the vertical semicircular canals of the affected labyrinth.

Current VHIT systems do not automatically detect this incongruent reflex, which may complicate the execution of the exam (traces rejected) or lead to an error in gain calculation for the LSC of the healthy side (pseudo-deficit). When an isolated vertical canal hypofunction is found, direct analysis of the

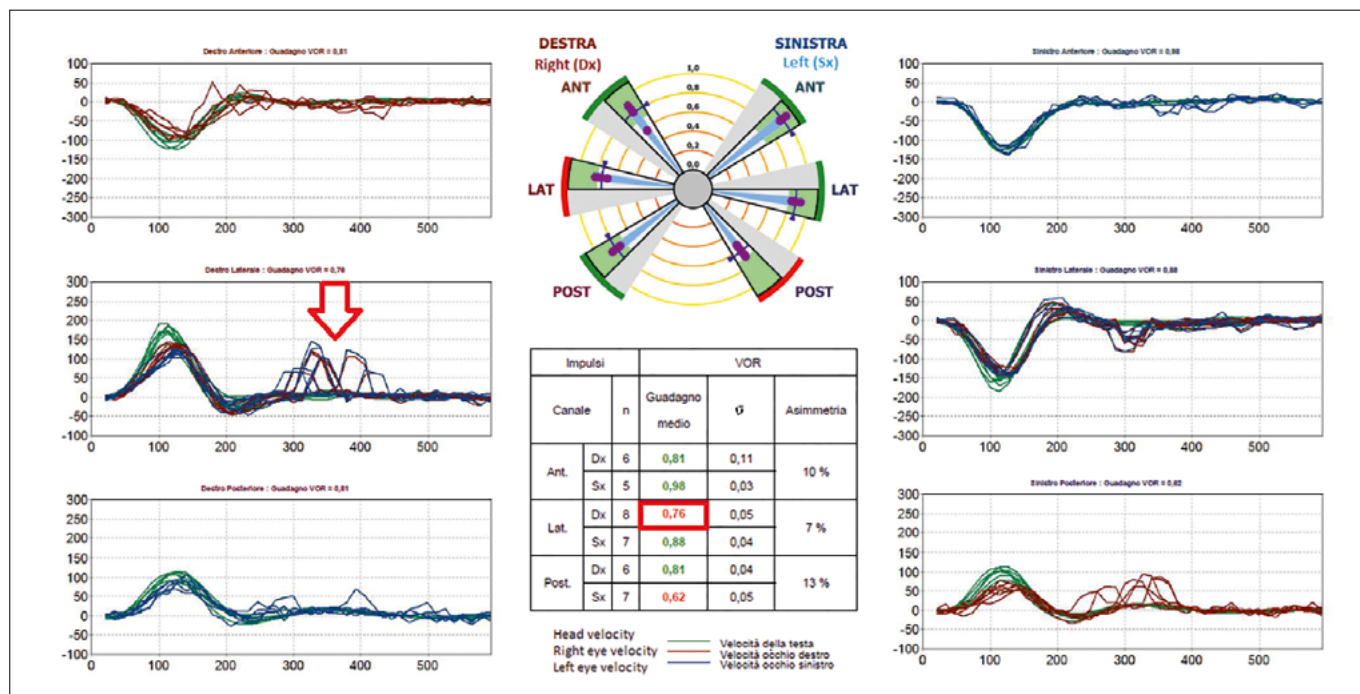


Figure 5. WHIT velocity traces of a patient with left PSC hypofunction and vertical saccades at right horizontal impulses. The red arrow highlights vertical saccades on the right LSC trace. The right LSC gain (highlighted) is below the normal range (pseudo-deficit).

video sequences acquired during horizontal impulsive movements is recommended to detect possible planar incongruences in eye responses. New algorithms for the WHIT systems are required to adequately signal eye movements that occur on planes other than the stimulated ones to allow correct evaluation of the eye movements reflected in cephalic impulses. Further studies are necessary to evaluate the temporal evolution of this clinical sign and its relation to specific pathologies.

Conflict of interest statement

The authors declare no conflict of interest.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author contributions

Fd’O: ideation and writing the paper; LN: English translation and correction; GN: supervision and correction paper.

Ethical consideration

The research was conducted ethically, with all study procedures being performed in accordance with the requirements of the World Medical Association’s Declaration of Helsinki. Written informed consent was obtained from each participant/patient for study participation and data publication.

References

- Walker MF, Zee DS. Cerebellar disease alters the axis of the high-acceleration vestibuloocular reflex. *J Neurophysiol* 2005;94:3417-3429. <https://doi.org/10.1152/jn.00375.2005>
- Jeong SH, Kim JS, Baek IC, et al. Perverted head impulse test in cerebellar ataxia. *Cerebellum* 2013;12:773-775. <https://doi.org/10.1007/s12311-013-0480-0>
- Yang CJ, Lee JY, Kang BC, et al. Quantitative analysis of gains and catch-up saccades of video-head-impulse testing by age in normal subjects. *Clin Otolaryngol* 2016;41:532-538. <https://doi.org/10.1111/coa.12558>
- d’Onofrio F. Vertical eye movements during horizontal head impulse test: a new clinical sign of superior vestibular neuritis. *Acta Otorhinolaryngol Ital* 2013;33:418-424.
- Koohi N, Mendis S, Lennox A, et al. Video head impulse testing: pitfalls in neurological patients. *J Neurol Sci* 2022;442:120417. <https://doi.org/10.1016/j.jns.2022.120417>
- Suh MW, Park JH, Kang SI, et al. Effect of goggle slippage on the video head impulse test outcome and its mechanisms. *Otol Neurotol* 2017;38:102-109 <https://doi.org/10.1097/MAO.0000000000001233.5>
- Mantokoudis G, Saber Tehrani AS, Kattah JC, et al. Quantifying the vestibulo-ocular reflex with videooculography: nature and frequency of artefacts. *Audiol Neurootol* 2015;20:39-50. <https://doi.org/10.1159/000362780>
- Della Santina CC, Potyagaylo V, Migliaccio AA, et al. Orientation of human semicircular canals measured by three-dimensional multiplanar CT reconstruction. *J Assoc Res Otolaryngol* 2005;6:191-206. <https://doi.org/10.1007/s10162-005-0003-x>
- Castellucci A, Piras G, Del Vecchio V, et al. Which inner ear disorders lie behind a selective posterior semicircular canal hypofunction on video head impulse test? *Otol Neurotol* 2021;42:573-584. <https://doi.org/10.1097/MAO.0000000000002995>