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Assessment of Vestibulo-ocular Reflex Gain and Catch-up Saccades During Vestibular Rehabilitation

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Objective: To assess, in patients referred to vestibular rehabilitation (VR) for persistence of disability after acute unilateral vestibulopathy (AUV), whether the video head impulse test (vHIT) can be a useful technique to define the efficacy of the treatment.
Study Design: Prospective clinical study.
Setting: Tertiary academic referral hospitals.
Patients: Thirty patients with residual symptoms after AUV were included.
Intervention: Patients underwent a 10-week VR program.
Main Outcome Measures: Evaluation of dizziness handicap inventory score, high-velocity vestibulo-ocular reflex gain, asymmetry index, and catch-up saccade parameters before and after VR.
Results: All patients reported a clear clinical improvement after VR, also demonstrated by better dizziness handicap inventory scores ($p < 0.001$). A consistent increased gain and decreased asymmetry index were also observed ($p < 0.001$ for both). Patients did not show any change in covert catch-up saccades, while a statistically significant reduction of the number and amplitude of the overt catch-up saccades was interestingly detected ($p = 0.009$ and $p = 0.030$, respectively).
Conclusion: VR is a valid approach for patients with residual disability after AUV. A reduction in number and amplitude of overt catch-up saccades seems useful to evaluate the efficacy of VR and to be related to clinical improvement. **Key Words:** Acute unilateral vestibulopathy—Dizziness—Outcome—Saccades—Vertigo—Vestibular rehabilitation—Video head impulse test.

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Acute unilateral vestibulopathy (AUV) is characterized by impairment of vestibulo-ocular reflex (VOR) and vestibulo-spinal reflex. Because of the deteriorated static and dynamic function of both reflexes, patients complain of dizziness, visual or gaze disturbances, and balance disorders (1).

After AUV most patients recover spontaneously. However, literature reports that approximately 50% of patients do not, developing chronic dizziness, disequilibrium, spatial disorientation, and limitations in daily activities (2–5). Current management of these chronic symptoms after AUV includes exercise regimes known collectively as vestibular rehabilitation (VR).

The use of VR has exponentially increased over the last 25 years and it is now widely accepted. It has proven its efficacy in reducing the symptoms and improving posture, gait, gaze stabilization, and quality of life (6). The goal of VR is to use a problem-oriented approach to promote compensation, which is achieved by customizing exercises to address the specific problems of each person.

Several outcome measures have been proposed to assess the impact of vestibular dysfunction and the recovery after VR; however, there is no consensus as to what aspects of function should be measured (7). Among the vestibular instrumental tests able to provide objective information about the impairment, posturography is the most widely used (8–10). However, posturography studies the vestibulo-spinal reflex alone providing above all information about the patient's balance. At the same time, it is known that many patients who suffered AUV complain of symptoms due to the deteriorated gaze stability caused by the abnormal VOR. To date, only tests evaluating visual acuity during head movement [dynamic visual acuity (DVA)] and subjective questionnaires are used to assess the impairment of VOR function.

Interestingly, gaze-stability exercises included in the VR program are described contributing to improvements in DVA in patients with unilateral vestibular dysfunction (11). This improvement can reflect a change in vestibular function and in VOR ability. Among the techniques able to study the VOR, video head impulse test (vHIT) constitutes a recently introduced method quantifying the high velocity semicircular canal function as VOR gain (12). VOR gain is a frequently used physiological

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measure of VOR function, able to differentiate patients with vestibular hypofunction from patients who have not. A VOR gain lower than 0.68 has been proposed as cut-point between normal and abnormally low VOR gain (12). The relative right-left asymmetry VOR gain ratio (AI%), automatically determined by some vHIT software, expresses the asymmetrical response to head rotation. A pathologically increased AI% is described in peripheral AUV respect to other acute vestibular syndrome (13,14).

To date some vHIT software also provides analysis of the compensatory catch-up saccades (CSs) that occur to compensate for a deficient VOR and the resulting gaze-instability, offering new interesting perspectives (15,16).

In this study we describe changes in VOR gain, AI%, and CSs in patients we referred to VR for residual dizziness after AUV; our aim was to determine whether the vHIT could be a useful technique to evaluate the outcome after VR in this category of patients.

METHODS

We prospectively analyzed 30 patients who underwent VR therapy for residual dizziness after AUV. All patients referred to our Neurotology service (Pisa University Hospital) in the period lasting from January 2015 and July 2016. They all underwent only routinely-performed tests, without invasive or experimental procedures. Informed consent was obtained from all participants and the study was conducted in accordance with the Declaration of Helsinki.

The diagnosis of AUV was based on: rapid onset of severe dizziness without either neurological or audiological symptoms, unidirectional horizontal nystagmus, unilateral canal paresis greater than 25% on bithermal caloric test, positive clinic head impulse test in the direction opposite to the fast phase of the nystagmus (17,18).

We advise VR when a patient complains of incomplete clinical recovery and has difficulty returning to daily activities after AUV. In our clinic VR consists of weekly supervised hospital evaluations and daily exercise training at home; the former have the purpose to correct mistakes during the execution of the exercises, document improvement, and progressing the exercises protocol. Each VR program lasted 10 ± 2 weeks depending on the residual symptoms reported by the patient. Patients were asked to perform exercises aimed at correcting both oculomotricity and posture 4 to 5 times per day for a total of about 30 minutes. The gaze stability exercise protocol we used was similar to the protocol described by Herdman et al. (11), which has been established to improve DVA in patients with unilateral vestibulopathy.

All patients enrolled in this study were examined at the beginning of VR (4–8 weeks after the onset of AUV) and at the end of the program; the main outcome measures were the Italian version of the dizziness handicap inventory form (DHI) (19) and vHIT.

The vHIT was performed by employing a dedicated device (ICS Impulse system; GN Otometrics, Taastrup, Denmark). The device software calculates automatically the average of the high-velocity VOR gain. The software calculates the AI% according to the ICS Impulse ''relative asymmetry'' formula: $[1 - (\text{lower high-velocity VOR gain mean}/\text{higher high-velocity VOR gain mean})] \times 100$. The last ICS Impulse firmware (4.0) allows tracking single CSs, automatically classified as ''covert'' or ''overt'' if generated during or after the head movement respectively. The prevalence of all tracked CSs (both covert and overt) during the whole series of impulses is provided and has been considered in the analysis. For each saccade, the software provides also values of latency and amplitude. Averaged values of covert and overt CSs latency and amplitude have been considered in the analysis for each patient. The software calculates the ''PR'' index, which represents the scattering pattern of the saccades latency after the stimulus: a lower PR value would suggest more gathered catch-up saccades.

Statistical Analysis

The Kolmogorov–Smirnov test was used to assess normal distribution of data. Differences between parametric and non-parametric data were assessed with paired sample t test and with Wilcoxon test, respectively. Significance was set at $p < 0.05$. The analyses were performed using SPSS software, 23th version (IBM, Chicago, IL).

RESULTS

All patients completed the study with a good compliance (execution of more than 70% of exercises), which was assessed per self-report during the supervised visit. The mean age was 61.66 (range 41–76) and there were 17 males and 13 females. All patients reported a clinical improvement after VR, also demonstrated by better DHI scores (Wilcoxon Test $p < 0.001$) (Fig. 1). A consistent increased VOR gain and decreased AI were also observed (paired t test $p < 0.001$ for both) (Figs. 2 and 3). Patients did not show statistically significant changes in covert CSs regarding any of the parameters considered. A statistically significant reduction of the number and amplitude of the overt CSs was interestingly detected (Wilcoxon test $p = 0.009$ and paired t test $p = 0.030$, respectively) (Figs. 4 and 5); conversely, PR score and latency of overt CSs were no significantly changed after VR. All the results are shown in detail in Table 1.

DISCUSSION

Many patients complain of chronic symptoms because of the incomplete recovery after AUV and VR represents a valid and widely accepted therapeutic option.

All patients enrolled in this study reported improved symptoms after VR and to be mostly returned to their daily activities. Therefore, our data confirm the safe and efficacy of VR therapy in AUV patients who do not recover spontaneously, in accordance with the literature (7,20).

The statistically significant better DHI scores after VR confirmed the efficacy of the treatment. The DHI constitutes one of the most commonly used measures based on patient's reported outcome and represents the main symptom scale we use during the follow-up of AUV patients. Our choice is supported by a recent systematic review that describes the DHI as a good and validated instrument applicable also in older adults with vestibular impairment (21).

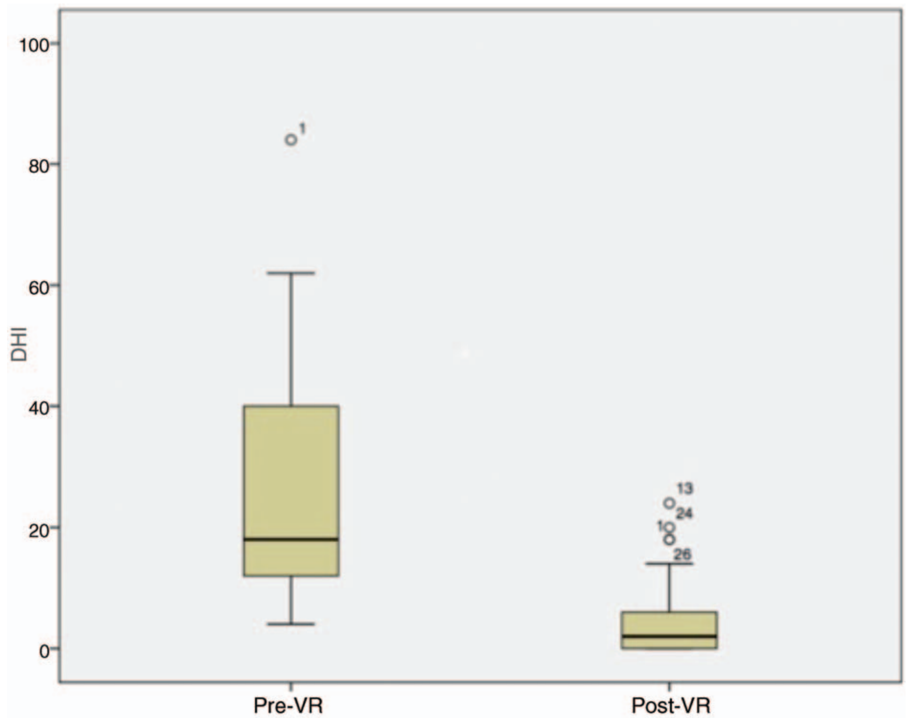

FIG. 1. Different responses to the dizziness handicap inventory (DHI) before and after vestibular rehabilitation (VR) ($p < 0.001$).

The purpose of our study was to investigate the vHIT as useful outcome measure of treatment during VR in patients with chronic symptoms after AUV.

To our knowledge this is the first study about this topic. Since our experience confirmed the usefulness of VR in this category of patients, our data seems to relate the efficacy of the treatment with modification in VOR

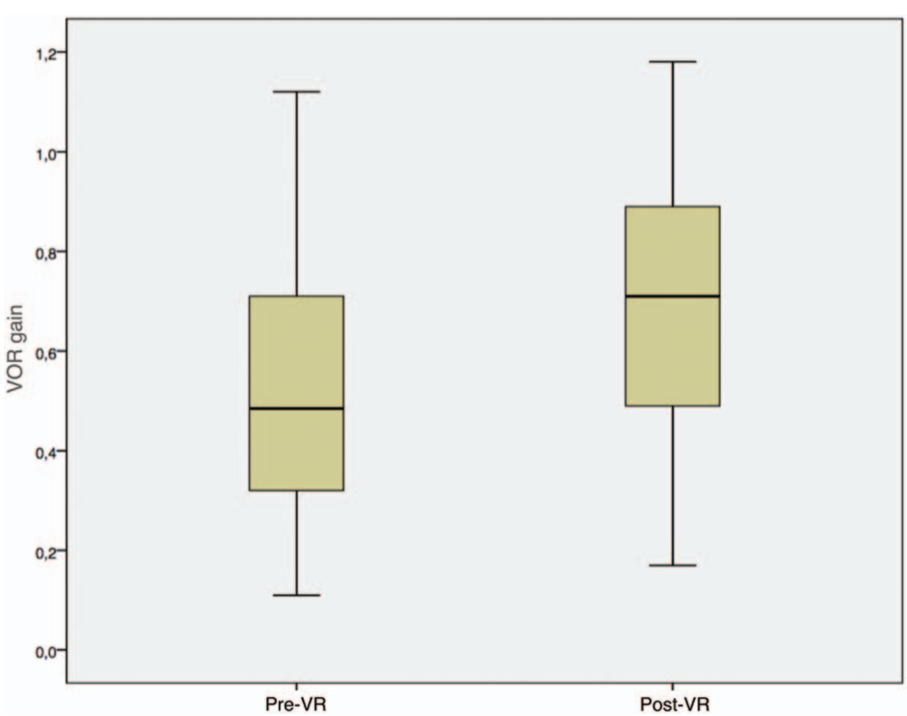

FIG. 2. Different responses to the video head impulse test in terms of high-velocity vestibulo-ocular (VOR) reflex gain before and after vestibular rehabilitation (VR) ($p < 0.001$).

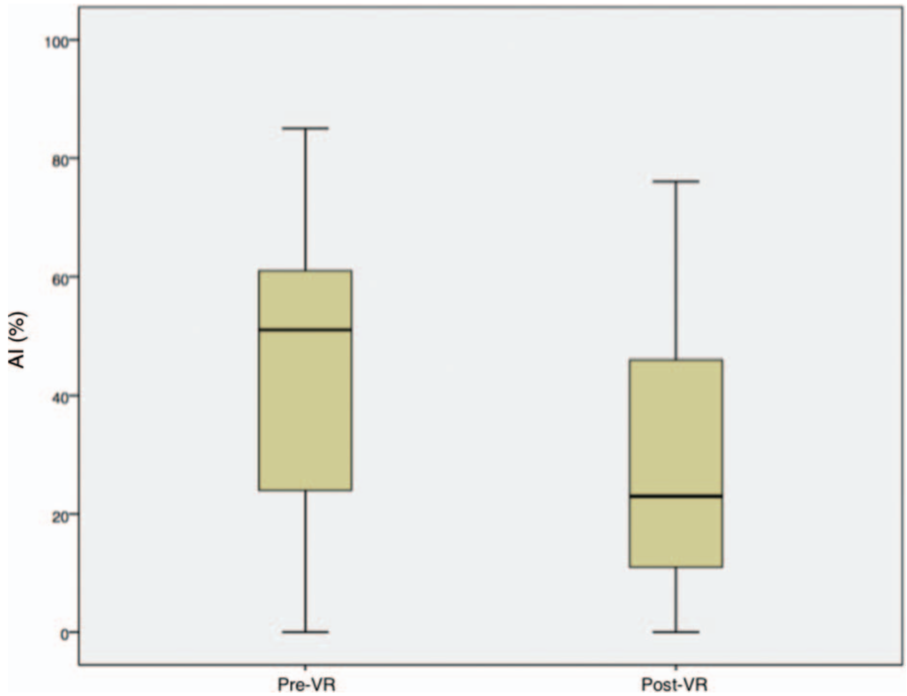

FIG. 3. Different responses to the video head impulse test in terms of Asymmetry Index (AI) before and after vestibular rehabilitation (VR) ($p < 0.001$).

gain values and CSs features. In particular, an increased VOR gain in association to a reduction in number and amplitude of overt CSs would be able to predict a good outcome after VR; on the other hand, the analysis of covert CSs seems to be no interesting for the same purpose.

From literature we know that gaze stabilization exercises improve visual acuity during head rotation and

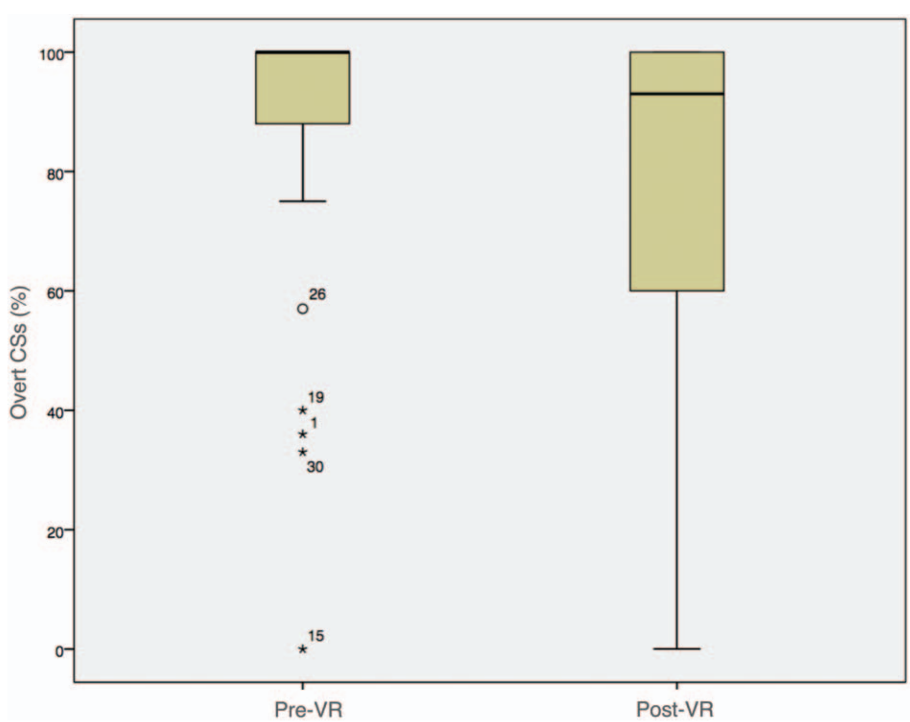

FIG. 4. Different responses to the video head impulse test in terms of presence of Overt catch-up saccades before and after vestibular rehabilitation (VR) ($p = 0.009$).

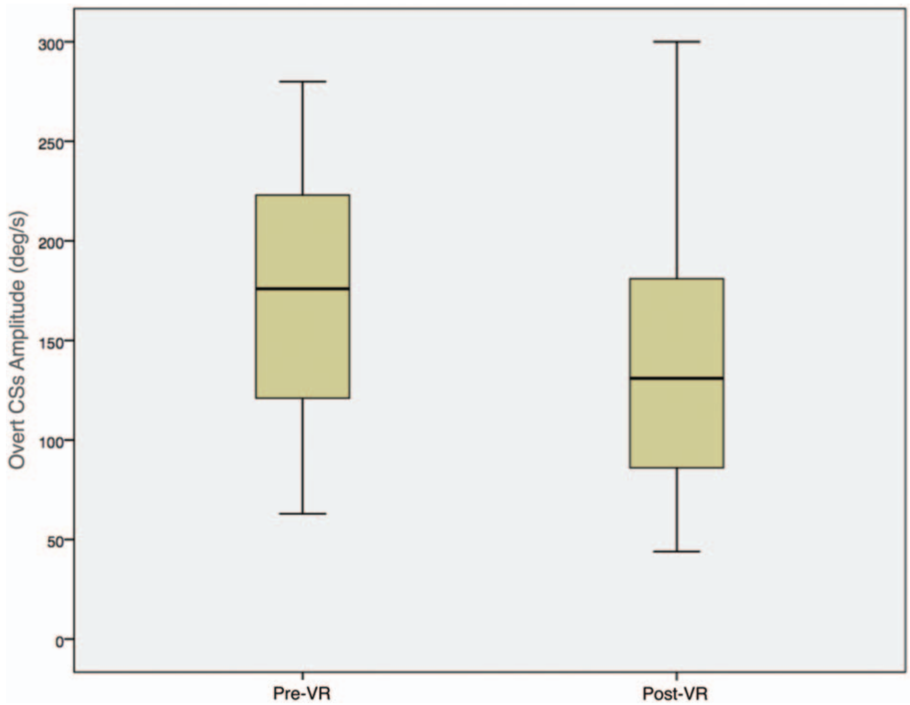

FIG. 5. Different responses to the video head impulse test in terms of Amplitude (Amp) of Overt catch-up saccades before and after vestibular rehabilitation (VR) ($p = 0.030$).

changes in VOR gain and CSs parameters as those we identified in our study can contribute to this recovery providing some useful information to define the outcome after VR.

Interestingly, the findings observed in our study perfectly agree with previous report about the analysis of CSs in AUV patients (16). The parameters established to be related to incomplete spontaneous recovery (lower high-velocity VOR gain, increased AI, increased overt CSs number and amplitude) are the same significantly improved after VR in this study, defining a good clinical outcome. Therefore, the analysis of VOR gain and overt CSs prevalence and amplitude seems to provide useful information about the recovery in AUV patients in spite of covert CSs. Overt CSs latency was averagely augmented but not statistically different after VR in our study.

Previous studies have analyzed catch-up saccades. Some of these report a relationship between overt CSs and VOR gain. In particular, Anson et al. (22) found a relationship between VOR gain and overt CSs amplitude and latency using the vHIT. They observed how individuals with lower VOR gain make a greater number of larger amplitude and shorter latency CSs, suggesting

TABLE 1. *Results of the Instrumental Assessment Before and After the VR*

	Pre-VR				Post-VR				
	Mean	Min	Max	SD	Mean	Min	Max	SD	*p* Value
High-velocity VOR gain	0.52	0.11	1.12	0.24	0.69	0.17	1.18	0.25	<0.000*
AI (%)	44.16	0.00	85.00	23.48	29.07	0.00	76.00	22.69	<0.000*
DHI	25.80	4.00	84.00	18.94	5.06	0.00	24.00	6.88	<0.000*
Covert CSs (%)	15.75	0.00	100.00	24.35	14.70	0.00	75.00	21.33	0.717
Covert CSs latency (ms)	110.33	85.00	167.00	22.13	108.00	80.00	144.00	18.72	0.710
Covert CSs amplitude (°/s)	188.00	64.00	286.00	67.33	169.36	50.00	294.00	75.19	0.796
Covert CSs PR	37.00	9.00	73.00	20.11	20.90	0.00	57.00	18.37	0.157
Overt CSs (%)	85.82	0.00	100.00	26.36	73.40	0.00	100.00	37.31	0.009*
Overt CSs latency (ms)	192.92	136.00	320.00	39.28	201.19	136.00	392.00	56.00	0.537
Overt CSs amplitude (°/s)	159.64	4.00	280.00	73.98	141.84	44.00	300.00	65,48	0.030*
Overt CSs PR	47.54	10.00	93.00	22.82	46.76	0.00	95.00	28.70	0.695

Significant *p* values are marked with an asterisk (*).

VOR indicates vestibulo oculomotor reflex; AI (%), asymmetry index; DHI, dizziness handicap inventory; CSs, catch-up saccades; PR, catch-up saccades scattering index.

quantitative analysis of overt CSs as additional tool to characterize age related changes to vestibular function. According to Anson et al. (22), overt CSs would functionally impact overall gaze stability. The same authors state that overt CSs need to be considered as measure of the compensatory quality of the VOR, reflecting the suitability of this reflex to the task of visual stabilization. Differently, Tian et al. (23), who did not analyze CSs after head movements, describe an association between the amplitude and latency of covert CSs and VOR gain. However, methodological differences could explain these conflicting findings. More recently, Cerchiai et al. (16) observed that VOR gain was negative correlated to overt CSs prevalence, and both covert and overt CSs amplitude while it was positive correlated with overt CSs latency. Interestingly, a case reported by Schubert et al. (24) from a patient with AUV described a dynamic relationship between the recruitment of CSs and VOR gain. In particular, they observed reduced CSs prevalence, amplitude, and latency, as VOR gain recovered assuming changing in CSs features from primarily overt to covert depending on VOR gain. Our data are partly concordant and partly discordant with these results; probably further studies including a greater sample of patients might shed light and clarify these conflicting results.

Although further studies are needed, the data we report could be of great interest to better assess the patient during VR; vHIT might be eventually combined either with posturography or with questionnaires already used as outcome measures. In particular, the lack of changes in the above mentioned vHIT parameters could provide information about gaze-stabilization improvement promoted by VR.

Our study presents some limitations. First, we did not consider a control group. Given the well-established role of VR in patients with residual dizziness after AUV (7,20), in our opinion the risk was to definitely compromise the recovery of patients. Moreover, our purpose was not to prove the efficacy of VR but rather to describe changes in vHIT parameters. Second, for the analysis we did not consider the data derived from vHIT on vertical canals: although some experiences report interesting data (25), we retain they are still subjects to some artifacts according to the literature (26). Lastly, we did not take into account posturography. Although vHIT and posturography assess different vestibular output, surely further study comparing the 2 techniques during VR could be of great interest.

Despite the above-described limitations, vHIT seems a new useful technique to define the outcome of VR.

CONCLUSIONS

VR is a valid approach for patients with chronic symptoms after AUV. The vHIT seems to be useful for defining the efficacy of the treatment. In particular, an increased VOR gain and a reduction in number and amplitude of overt CSs are likely to predict a good outcome after VR. Although further studies are needed, these findings constitute objective measures of outcome that could be of great interest for clinician to evaluate the improvement of patients during VR.

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