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ORIGINAL COMMUNICATION

The functional head impulse test: preliminary data

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Abstract
The functional head impulse test is a new test of vestibular function based on the ability to recognize the orientation of a Landolt C optotype that briefly appears on a computer screen during passive head impulses imposed by the examiner over a range of head accelerations. Here, we compare its results with those of the video head impulse test on a population of vestibular neuritis patients recorded acutely and after 3 months from symptoms onset. The preliminary results presented here show that while both tests are able to identify the affected labyrinth and to show a recovery of vestibular functionality at 3 months, the two tests are not redundant, but complementary.

Keywords Functional vestibular testing · Head impulse test · fHIT · Vestibular neuritis · Vestibular rehabilitation assessment

Introduction

The seminal work of Halmagyi and Curthoys introduced the clinical use of abrupt transients of head rotation (head impulses) as a technique for unveiling unilateral vestibular deficits even in chronic patients [4]. Clinically, the technique would consist in asking the patient to maintain fixation on a stationary target, typically the nose of the examiner, while his/her head is passively, abruptly rotated to one side. During the maneuver, the examiner closely looks at the patient's eyes looking for the occurrence of a fast corrective movement bringing the eyes back on target at the end of the head movement, which would represent the clinical sign of a deficit in the excited semicircular canal (overt saccade). While classical vestibular testing approaches, both in the clinic and in the laboratory, mostly relied on low-frequency stimuli, such as with calorics or vestibular chair sinusoidal and post-rotatory stimuli, the introduction of the head impulse test (HIT) technique extended the range of tested frequencies and exploited the asymmetric behavior to excitation and inhibition of each semicircular canal summarized by Ewald's second law [5]. Recently, with the introduction of light-weight high-speed cameras, the video head impulse test (vHIT) [7, 15, 16] has become of widespread use both in the clinic and in private practice.

Thus, the quantitative head impulse test provides as output a gain value that summarizes the behavior of the vestibulo ocular reflex as the ratio of a measure of eye movement to the corresponding one of head movement. A deficient rVOR gain would then be an indicator of dysfunction in the semicircular canal towards which the head is rotated. It is an objective measure that quantifies the behavior of the VOR either as a temporal average or as an instantaneous value, fundamental in tuning a mathematical model, yet not directly informative of the functional effectiveness of the

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motor response: allowing good gaze stabilization to permit clear vision. In other words, the quantitative HIT provides a number indicating whether the VOR produces the intended eye movement but does not inform the clinician on whether the patient is able to use such eye movement for viewing clearly during the head movement, and hence fulfill the functional goal of the rVOR response.

Such functional goal of the rVOR, on the other hand, has provided the grounds for the development of alternative techniques aimed at assessing the function of the rVOR in terms of its efficacy towards allowing clear vision. The task does not require to compute the gain of the reflex and can, therefore, be accomplished without recording the movement of the eyes, which makes the functional testing approach easier, requiring less-expensive equipment and applicable to a broader range of patients, such as children or patients with ptosis, than the classical, gain-based, evaluation of the rVOR.

All three current functional vestibular testing approaches, i.e. the dynamic visual acuity test (DVAT) [6, 12], the gaze stabilization test (GST) [3, 9] and the functional head impulse test (fHIT) [1, 11, 14] are based on requiring the patient to identify an optotype displayed on a computer screen during head rotations, yet they differ in terms of visual stimulus triggering criteria and outcome measure: a change in visual acuity measure (logMAR) for the DVAT, the maximum head velocity that does not reduce visual acuity for the GST, the percentage of correctly identified optotypes during head rotations within a range of head angular accelerations for the fHIT. Diagnosis with these techniques is based on the comparison of the patient's behavior with that of healthy subjects in the same task.

Here, we have investigated the most recently proposed technique, the fHIT, and compared its results with those of the vHIT and with the results of the Dizziness Handicap Inventory (DHI) questionnaire [2] in a group of vestibular patients recorded acutely and at 3-month follow-up. We predicted to find a relatively good correlation of the results of the two techniques, assuming that the VOR would be the most relevant contributor to gaze stabilization, yet some discrepancy, possibly related to the role of covert saccades, could be expected [10, 17].

Materials and methods

We recorded 27 vestibular neuritis patients (age 55.33 ± 12.02, 15 were male), 3–7 days (4.81 ± 1.24 days, mean ± SD) after the onset of symptoms, when spontaneous nystagmus had disappeared or was greatly reduced. The diagnosis of vestibular neuritis was made in case of an acute onset rotatory vertigo, with an horizontal–torsional nystagmus beating in the same direction in all orbital positions, partially inhibited by visual fixation, enhanced by head shaking test, with a positive clinical head impulse test and no skew deviation; the neurological examination had to be normal and in some patients the diagnosis was confirmed by a negative brain MRI. Caloric testing with hot, cold, and ice water was performed. Asymmetry of vestibular function with calorics was calculated using the Jongkees formula and a paresis was defined when there was some response on both sides but the difference between the two ears was 30% or more. A paralysis was defined when there was no response to ice water irrigation on one side [8]. Caloric paralysis was identified in 22 subjects and paresis in five patients (80.63 ± 10.50 asymmetry).

vHIT was performed using the ICS Impulse (Otometrics, Natus Medical Inc) system delivering at least 20 impulses in each horizontal direction and vHIT gain results were considered abnormal when less than 0.8, as specified by the manufacturer for their system. At the time the recordings were performed, spontaneous nystagmus was absent in the light in 23/27 subjects. It was largely reduced also in the remaining four patients, but eye movements were not recorded.

fHIT was performed using the fHIT system (Beon Solutions srl), delivering at least 20 impulses in each direction in the horizontal canals plane, and its results were compared with those of a group of 30 age-matched, healthy subjects tested with the same technique, based on the standardized normal deviate of the patient falling outside the 99% of the two-tailed z distribution [11, 13]. DHI was performed only at 3 months, to evaluate residual subjective symptoms, but, unfortunately, was not recorded acutely.

We considered the gain (g) values of vHIT and the percentage of correct answers (% CA) of fHIT both from the healthy and affected side at both the onset of vestibular neuritis and after 3 months.

As for the caloric testing (that was performed only at onset), we computed both for vHIT and for fHIT an asymmetry index, expressed as a percentage, as (healthy − affected)/(healthy + affected).

The mean values were compared by repeated measures analysis of variance with three two-level within-subject factors: side (healthy vs affected), time (onset vs 3 months), technology (video vs functional HIT) and their interactions.

For the asymmetry indices, we performed a similar analysis, but we considered as factors only the time and the technology.

We checked for possible significant correlations between the different parameters and the DHI score evaluated at 3 months.

We also compared the percentage of abnormal patients for both g and % CA.

The significance level was set at $p = 0.01$ for all statistical analyses.

Data (Fig. 1) were collected within the routine protocol exams for vestibular patients performed at the

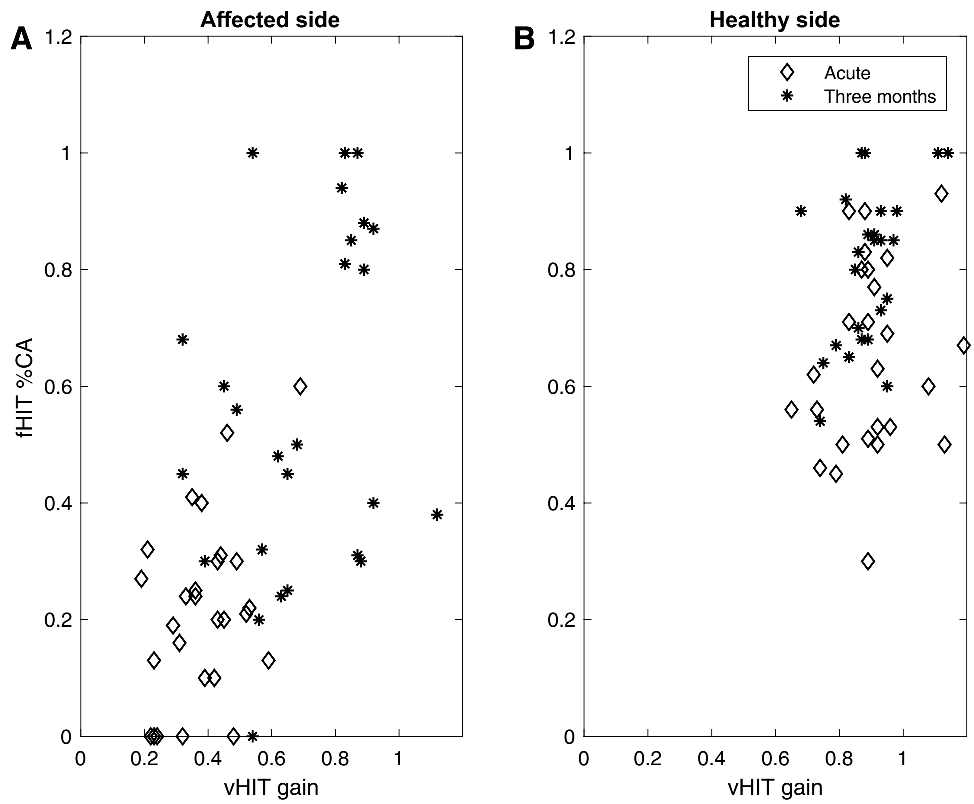

Fig. 1 % CA from fHIT plotted against the corresponding rVOR gain in the acute phase (empty diamonds) and at 3-month follow-up (stars). **a** Data from the side of the lesion and **b** data from the healthy side

Table 1 Descriptive statistics of rVOR gain and % of CA at both recording times

	Mean	SD
% CA fHIT affected onset	0.2148	0.15562
% CA fHIT healthy onset	0.6363	0.16701
% CA fHIT affected 3 months	0.5522	0.27647
% CA fHIT healthy 3 months	0.8263	0.13279
g vHIT affected onset	0.3830	0.12431
g vHIT healthy onset	0.9100	0.14079
g vHIT affected 3 months	0.7011	0.20746
g vHIT healthy 3 months	0.9193	0.13975
DHI 3 months	21.63	10.55

Table 2 Repeated measures analysis of variance and interactions between the three considered factors

	$F(1, 26)$	p
SIDE_	37.597	< 0.001
TIME_	133.358	< 0.001
TECH	281.595	< 0.001
SIDE_ * TIME_	12.897	0.001
SIDE_ * TECH	0.414	0.526
TIME_ * TECH	50.532	< 0.001
SIDE_ * TIME_ * TECH	4.842	0.037

Otolaryngology Unit of the Policlinico Le Scotte in Siena, as approved by the local Ethics Committee and all the procedures were conducted in accordance with the Declaration of Helsinki. All subjects gave written informed consent before participating in the study.

Results

The descriptive statistics of gain and % CA (means and standard deviations), together with those of the DHI at 3 months, are reported in Table 1.

The results of the repeated measures analysis of variance for both the gain and % CA values are shown in Table 2.

We found a significant effect of side (values from the affected side were lower than those from the healthy side), time (values at onset lower than at 3 months) and technology (fHIT values lower than vHIT values).

Table 3 Asymmetry indices for both techniques in acute and at 3 months

	Mean	SD.
g vHIT asymmetry onset	41.4317	14.57899
g vHIT asymmetry 3 months	14.9255	14.91053
% CA fHIT asymmetry onset	54.4337	27.96742
% CA fHIT asymmetry 3 months	25.1207	23.76224

The interaction between the side and the technology factor was not significant, and both the gain values and the % CA were lower in the affected than in the healthy side.

By contrast, we found a significant interaction between side and time: both the gain and the % CA increased after 3 months compared to the onset, but the increase was higher in the affected than in the healthy side.

Interestingly, the interaction between time and technology was also significant: after 3 months, both the gain and the % CA increased, but the increase was larger for % CA than for gain, in particular for the healthy side.

Finally, the interaction between the three factors was not significant.

The results of the repeated measures analysis of variance for both the gain and % CA asymmetry indices are shown in Tables 3 and 4.

The time factor proved to be significant, since for both the gain and the % CA, the asymmetry indices (reported in Table 3, analysis of variance in Table 4) were smaller after 3 months than at the onset of vestibular neuritis. The technology factor was significant also, since the indices were significantly larger for fHIT than for vHIT. The interaction between time and technology was not significant.

There was no significant correlation between the different vHIT and fHIT parameters and indices, or with the DHI values after 3 months.

The percentage of patients who proved to be abnormal varied depending on the technique, side and time of observation (Table 5).

At vestibular neuritis onset, both the gain and the % CA from the affected side were abnormal in all patients, but also from the healthy side in some of them. After 3 months, the two parameters improved, but still showed some abnormalities. The % of CA was abnormal more frequently than the *g* values and, with the exception of the affected side at onset, the percentage of abnormalities detectable by the two techniques were not significantly associated (chi-square analysis).

Finally, the mean DHI values were never significantly different when, for each parameter (% CA or vHIT gain), the patients were split in two groups depending on the abnormality of that parameter.

Table 4 Results of the analysis of variance of asymmetry indices

	F (1, 26)	p
TIME_	9.155	0.006
TECH	74.806	< 0.001
TIME_ * TECH	0.164	0.689

Table 5 Percentage of abnormal patients for both the gain of vHIT and the % CA of fHIT, from both the affected and the healthy side both at onset of vestibular neuritis and 3 months after

	g vHIT	% CA fHIT
Onset		
Affected	100	100
Healthy	18.5	88.9
3 months		
Affected	51.9	85.2
Healthy	14.8	51.9

Discussion

Both the vHIT and fHIT exams correctly classified all patients as abnormal in the affected side when tested in the acute phase; after a 3-month follow-up both were able to show that compensation phenomena have occurred.

Otherwise, the data from the two techniques were not correlated. More specifically, the fHIT detected more abnormalities than the vHIT, in particular concerning the healthy side, both in the acute phase and after 3 months, and the affected side after 3 months. The asymmetry indices also were larger for the fHIT than for the vHIT both at onset and after 3 months.

Overall, the data from the fHIT, but not form the vHIT, are able to show that, despite the gain values from the healthy side are close to normal, the VOR is functionally impaired. The same behavior is shown by the compensation phenomena that seem to improve gain values more than the capability to read while moving.

Despite the capability to pinpoint a functional impairment, both the vHIT and the fHIT results do not correlate with the patients' self-feeling about their imbalance evaluated by DHI questionnaire. This finding was somewhat surprising for the fHIT results, hinting that vestibular compensation involves more factors than only gaze stabilization. In fact, the DHI is a generic tool for assessing perceived disability related to dizziness, which may be due to central, peripheral and psychogenic vestibular disorders, and does not necessarily relate to the residual symptoms in vestibular neuritis. Accordingly, a recent publication also found no correlation between the results of the DHI questionnaire and those of the vHIT, calorics or posturography in a group of peripheral patients and found them not different from those on healthy subjects [18].

Conclusions

We demonstrate that the fHIT data are in keeping with their expected behavior, since they are able to detect a difference between the healthy and the affected side in the acute phase, and they show an improvement after 3 months. fHIT detects more abnormalities than vHIT, but both these techniques lack a correlation with the DHI score.

Overall, these findings must be considered as preliminary, but they suggest that the fHIT and vHIT are complementary techniques for the evaluation of vestibular function and compensation.

Compliance with ethical standards

Conflicts of interest Marco Mandalà and Stefano Ramat are authors of a Patent Deposit Application regarding the technique used in the functional head impulse test and, together with Maurizio Versino, they are shareholders of a company producing a commercial version of fHIT.

Ethical standard Data were collected within the routine protocol exams for vestibular patients performed at the Otolaryngology Unit of the Policlinico Le Scotte in Siena, as approved by the local Ethics Committee and all the procedures were conducted in accordance with the Declaration of Helsinki. All subjects gave written informed consent before participating in the study.

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