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Gulce Kirazli , Sevinc Hepkarsi & Tayfun Kirazli

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ARTICLE

Evaluation of high frequency horizontal VOR parameters in patients with chronic bilateral and unilateral peripheral vestibulopathy: a preliminary study

Gulce Kirazli[a], Sevinc Hepkarsi[b] and Tayfun Kirazli[b]

[a]Audiometry Program, Ataturk Health Services Vocational High School, Ege University, Izmir, Turkey; [b]Otorhinolaryngology Department, School of Medicine, Ege University, Izmir, Turkey

ABSTRACT
Background: Caloric test is one of the tests which evaluates the low frequency component of vestibular system for both diagnosis of the BPV and UPV.
Aims: The main objectives are to determine and increase the diagnostic value of BPV and UPV by evaluating the high frequency horizontal VOR parameters with HIMP, SHIMP and fHIT, to compare test results with healthy controls, and to evaluate correlation of these tests with vertigo dizziness imbalance (VDI) questionnaire results in these patients.
Material and methods: Six patients with BPV, ten patients with UPV and fifteen healthy controls were recruited. High frequency hVOR were evaluated with HIMP, SHIMP and fHIT. Vestibular symptoms and quality of life were assessed with VDI Questionnaire.
Results: Lower percentage of correct answers, and lower VOR gains were obtained in affected sides for BPV and UPV. HIMP elicited compensatory saccades in patients, whereas SHIMP elicited large anti-compensatory saccades in controls and unaffected side of UPV, but no saccades in BPV. No correlation was found between VDI outcomes and all tests.
Conclusions: The results show that all tests are complementary each other and able to identify the affected labyrinth and to show residual vestibular function. These tests are thought to be important in the vestibular rehabilitation process.

Abbreviations: BPV: Bilateral Peripheral Vestibulopathy; CA%: Percentage of Correct Answers; ENT: Ear Nose Throat; fHIT: Functional Head Impulse Test; HIMP: Head Impulse Test Paradigm; hVOR: Horizontal Vestibulo-Ocular Reflex; LL: Left Lateral; RL: Right Lateral; SCC: Semi-Circular Canals; SHIMP: Suppression Head Impulse Paradigm; SPSS: Statistical Package for Social Sciences; UPV: Unilateral Peripheral Vestibulopathy; VDI: Vertigo Dizziness Imbalance; VDI-HQoL: Vertigo Dizziness Imbalance-Health-related Quality of Life Scale; VDI-SS: Vertigo Dizziness Imbalance- Symptom Scale; vHIT: Video Head Impulse Test; VEMP: Vestibular Evoked Myogenic Potentials; VOR: Vestibulo-Ocular Reflex

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KEYWORDS
Functional head impulse test; head impulse test; suppression head impulse paradigm

Introduction

High frequency (2–6 Hz) vestibulo-ocular reflex (VOR) has played an important role in visual stabilization, especially during daily activities [1,2]. Video head impulse test (vHIT), today known as the HIT paradigm (HIMP) and functional head impulse test (fHIT), is used to evaluate high frequency component of VOR at physiological frequencies (>1 Hz) in patients with different peripheral dysfunctions. vHIT has provided a quantitative value indicating whether the VOR has produced the desired eye movement or not; however, it does not give the clinician an idea of whether the patient uses eye movements for clear vision during the head movement [3]. Therefore, fHIT technique has been developed in order to meet the functional purpose of the VOR response [4]. Recently, suppression head impulse paradigm (SHIMPs), a variant of the HIMPs test, has been introduced [5,6]. It has measured VOR gain as HIMPs. In HIMP, no saccadic response has been considered as normal vestibular function. Thus, anti-compensatory saccades in the direction of the head movement can be thought as sign of a normal VOR during SHIMP in healthy people.

Traditionally, caloric test is one of the tests which evaluates the low frequency component of vestibular system for both diagnosis of the bilateral Vestibulopathy (BPV) and Unilateral vestibulopathy (UPV). The objectives of this study are (1) to determine and increase the diagnostic value of BPV and UPV by evaluating the high frequency horizontal VOR parameters with HIMP, SHIMP and fHIT, (2) to compare test results with healthy controls, and (3) to evaluate correlation of these tests with vertigo dizziness imbalance (VDI) questionnaire results in these patients.

Materials and methods

Participants

The study has been conducted as prospective and taken place in ENT department. The study has been done by following the ethical principles of Helsinki Declaration. Both

CONTACT Gulce Kirazli gulcekirazli@gmail.com Audiometry Program, Ataturk Health Services Vocational High School, Ege University, Izmir 35100, Turkey.

verbal and written informed consent have been obtained from all participants. Furthermore, the inclusion criteria of the study have not included history of acute, prolonged spontaneous vertigo; but it has consisted of a history of chronic imbalance, unilateral or bilateral total canal paresis (100%) on caloric testing and being 18–65 years old. Some participants with otological problems such as chronic otitis media, tympanic membrane perforation, outer ear atresia, metabolic disease, neurological, psychological and mental illness, severe visual impairment, and temporomandibular joint dysfunctions have been excluded from the study. The study has just included six patients with bilateral vestibulopathy, ten patients with unilateral vestibulopathy, and fifteen healthy asymptomatic controls.

Equipments

HIMP protocol

HIMP has been performed using EyeSeeCam (Interacoustics) system delivering at least 10 impulses in each horizontal direction; and the obtained results from HIMP have been considered as abnormal when less than 0.8 for horizontal semi-circular canals (SCCs). When overt or covert saccades have been available for >50% of the trials, it has been also accepted as abnormal in HIMP. Additionally, the result which has been obtained when the peak head velocities ranged between 150 and 250°/s with a 10°–20° amplitude is accepted [7].

SHIMP protocol

SHIMP follows the same protocol as HIMPs with an exception so the patient is instructed to follow the movement of a head-fixed laser spot on the wall during the passive head impulses. At least 10 head impulses have been performed randomly for each horizontal direction (right and left). Moreover, VOR gain of SHIMP has been calculated in the same way as in HIMP. Anti-compensatory saccades in SHIMP, unlike HIMP, indicate normal vestibular function [8].

Functional head impulse test (fHIT)

The participants have been placed 1.5 m from fHIT computer monitor by wearing a head mounted accelerometer in fHIT which has been conducted by using the fHIT system (Beon Solutions srl). The first one which has been evaluated is static visual acuity. During the Test, the participant is expected to look at the Landolt's C optotype in one of eight possible orientations that appear randomly on the computer screen; then they recognize it and select the correct C optotype while his/her head is being turned. At least 10 passive head impulses with an acceleration between 3000 and 6000 deg/s in each direction in the plane of the horizontal have been applied. The percentage of correct answers (CA%) has been recorded for impulses on both left and right [9]. This percentage has been considered as reflection of the high-frequency DVA (dynamic visual acuity). A CA% of <80 has been accepted as abnormal [4].

Vertigo dizziness imbalance (VDI) questionnaire

Vertigo, Dizziness, Imbalance (VDI) Questionnaire have evaluated self-report measure of vertigo, dizziness or imbalance symptoms and their impacts on patients' health-related quality of life [10]. The items in VDI which consists of two subscales like symptom scale (VDI-SS) with 14 items and health-related quality of life scale (VDI-HQoL) with 22 items are answered depending on a (0–5) Likert scale, (0: all of the time, 1: most of the time, 2: a good bit of the time, 3: some of the time, 4: a little of the time and 5: none of the time). It is determined that the total score is 60 for VDI-SS and 110 for VDI HQoL. As the score decreases in both VDI-SS and VDI- HQoL, the increase will occur in the level of symptoms and impact on quality of life. VDI Questionnaire's adaptation, the reliability and validity study of the Turkish version was done by Yanik et al. in 2008 [11].

Statistical analysis

While Man Whitney-*U* test was using in the comparison of two independent groups, Kruskal Wallis-H test was used to compare more than two unrelated groups and pairwise comparisons so as to determine the source of the difference. The relationship among the variables was examined by Pearson correlation coefficient by using Windows SPSS (statistical package for social sciences) version 22.0 (SPSS Inc. Chicago, IL) and considering p values below .05 statistically significant.

Results

Demographics

Categorical variables such as gender, age, duration of dizziness (month), canal paresis side of the unilateral group, diagnosis have been shown as frequency, but percentage and numerical data have been shown as mean standard deviation.

The study was consisted of thirty-one participants as 15 were healthy participants (mean age 51.40 ± 8.53; range 30–65), 6 were patients with bilateral peripheral vestibulopathy (BPV) (mean age 57.33 ± 6.53; range 47–65) and 10 were patients with unilateral peripheral vestibulopathy (UPV) (mean age 50.30 ± 10.02; range 34–65). The number of men and women in the groups was variable. For instance, it was determined that there were 4 men and 2 women in BPV, 4 men and 6 women in UPV and 7 men and 8 women in control groups. Otherwise, the mean time was stated as 45.50 ± 38.95 months (range 4–120 months) for UPV, but it was 137.00 ± 172 months (range 18–480 months) for BPV. Considering the BPV group, it was clear that the diagnosis was idiopathic for all patients. On the other hand, seven patients were diagnosed with meniere and three patients with vestibular neuritis in UPV group. Also, two patients with oscillopsia were in BPV. Seventy percent of patients had left unilateral total canal paresis in UPV group.

Table 1. Patients' demographics.

Patient	Vestibulopathy	Gender	Age	Diagnosis	Oscillopsia	Canal paresis side	Duration of dizziness (Month)
1	Bilateral	Man	47	Idiopathic	No	Bilateral	120
2	Bilateral	Man	54	Idiopathic	Yes	Bilateral	108
3	Bilateral	Woman	59	Idiopathic	Yes	Bilateral	480
4	Bilateral	Man	56	Idiopathic	No	Bilateral	36
5	Bilateral	Woman	63	Idiopathic	No	Bilateral	60
6	Bilateral	Man	65	Idiopathic	No	Bilateral	18
7	Unilateral	Man	38	Meniere	No	Right	84
8	Unilateral	Man	51	Meniere	No	Left	55
9	Unilateral	Woman	56	Meniere	No	Right	72
10	Unilateral	Woman	34	Meniere	No	Left	60
11	Unilateral	Woman	65	Vestibular Neuritis	No	Right	18
12	Unilateral	Man	50	Vestibular Neuritis	No	Left	12
13	Unilateral	Woman	65	Meniere	No	Left	6
14	Unilateral	Woman	50	Meniere	No	Left	24
15	Unilateral	Woman	47	Vestibular Neuritis	No	Left	4
16	Unilateral	Man	47	Meniere	No	Left	120

Table 1 shows detailed information about patients' demographics.

Comparison of fHIT results among groups

Kruskal Wallis-H test has been conducted so as to determine whether fHIT left lateral CA% and right lateral CA% variables are statistically difference among the groups or not. If there is difference, pairwise tests have been applied in order to understand that which group has the difference.

Statistically, significant difference was found among groups regarding CA% for both sides in fHIT ($p < .05$) (Table 2). Taking into account the multiple pairwise comparisons, CA% for both sides in control group was found higher when compared to BPV and UPV groups. It was found that the CA percentage was below 80% in all patients in the BPV group, but this ratio was below 80% in 9 of the 10 patients in the UPV group. On the other hand, there was no significant difference in terms of CA% on left and right sides within the groups ($p > .05$).

Comparison of HIMP and SHIMP results among groups

Kruskal Wallis-H test has been used so as to understand whether the RL and LL gain variables show statistically significant difference between the groups as a result of the HIMP and SHIMP tests. If there is difference, pairwise tests have been applied in order to understand that which group has the difference.

As a result, BPV group had lower VOR mean gain for both left and right ears. However, UPV group had lower VOR mean gain for left side compared to right side. Control group had normal VOR mean gain for both sides (Table 3). There was no significant difference in terms of HIMP and SHIMP VOR gain values for both ears within the groups ($p > .05$). Superscript value for bilateral group is 1; for unilateral group is 2; and for control group is 3. The VOR gain with SHIMP was smaller than for HIMP in all groups, but showed significant correlation in UPV ($r = 0.927$, $p < .001$; $r = 0.875$, $p < .001$, for right and left sides, respectively) and control groups ($r = 0.604$, $p < .001$, for left side). RL and LL VOR gain values showed a statistically significant difference among groups in both HIMP and SHIMP ($p < .05$). On the basis of the multiple pairwise comparisons, VOR gain values for both sides in BPV group was found lower in contrast with the control group (1<3).

Table 2. Findings regarding comparison of CA% in fHIT among groups.

fHIT	Group	n	Mean rank	$\bar{\bar{X}} \pm$ Ss	χ^2_{KW}	p	Difference
LL CA%	Bilateral	6	6.25	30.63 ± 37.32	19.214	.01	1.2 < 3
	Unilateral	10	11.30	61.90 ± 26.43			
	Kontrol	15	23.03	95.68 ± 6.786			
RL CA%	Bilateral	6	4.42	21.75 ± 13.66	20.912	.01	1.2 < 3
	Unilateral	10	12.30	67.54 ± 26.46			
	Kontrol	15	23.10	93.60 ± 8.692			

Table 3. Findings regarding comparison of VOR gains in HIMP and SHIMP among groups.

HIMP	Group	n	Mean rank	$\bar{\bar{X}} \pm$ Ss	χ^2_{KW}	p	Difference
HIMP							
RL	Bilateral[1]	6	5.08	0.59 ± 0.33	13.060	.01	1 < 3
	Unilateral[2]	10	15.25	0.93 ± 0.12			
	Control[3]	15	20.87	0.98 ± 0.06			
LL	Bilateral[1]	6	7.00	0.62 ± 0.38	11.60	.01	1 < 3
	Unilateral[2]	10	13.55	0.77 ± 0.33			
	Control[3]	15	21.23	1.01 ± 0.06			
SHIMP							
RL	Bilateral[1]	6	6.42	0.57 ± 0.31	9.75	.01	1 < 3
	Unilateral[2]	10	15.60	0.86 ± 0.12			
	Control[3]	15	20.10	0.91 ± 0.07			
LL	Bilateral[1]	6	7.00	0.59 ± 0.36	10.90	.01	1 < 3
	Unilateral[2]	10	13.95	0.73 ± 0.32			
	Control[3]	15	20.97	0.97 ± 0.08			

In HIMP, BPV patients made only overt saccades ($n = 3$), or a mixture of covert and overt saccades ($n = 3$). Patient with BPV had not any anti-compensatory saccades in both sides in SHIMP. UPV patients made only covert saccades ($n = 1$), only overt saccades ($n = 1$), or a mixture of covert and overt saccades ($n = 5$) in affected side. Six patients (60%) with UPV elicited anticompensatory saccades to the healthy side, unlike affected side, during SHIMP. Control group had not any catch-up saccades during HIMP. On the other hand, all participants in control group had large anti-compensatory saccades in SHIMP. A multitude of SHIMP saccades for both sides in control group and for unaffected side in UPV group indicate normal vestibular function.

Comparison of VDI-SS and VDI-HQoL Questionnaire Scores between groups

Mann-Whitney U test has been conducted in order to determine whether the VDI-SS and VDI-HQoL Scale Scores differ between bilateral and unilateral groups.

VDI-SS and VDI-HQoL scores for BPV group were 36.5 ± 16.42 and 54.6 ± 22.43, respectively and those scores were 43.6 ± 9.430 and 53.5 ± 15.29, respectively for UPV group. It was found that VDI-SS and VDI-HQoL scores could not show statistically significant difference in both bilateral and unilateral groups ($p > .05$). According to Pearson correlation coefficient test, there were not any correlation between VDI-SS and VDI-HQoL Questionnaire scores and fHIT, HIMP and SHIMP results for BPV and UPV groups.

Discussion

We suggest that the findings obtained from the HIMP, SHIMP, and fHIT tests in this study will contribute to evaluating the quantitative and functional impairment in VOR and to determining the affected side in severe bilateral or unilateral peripheral vestibular losses. This is the first comprehensive study; which evaluated the involvement of the high-frequency component of the horizontal VOR objectively with these three tests; as well as evaluating the relationship between VOR dysfunction and, subjective symptom severity of vertigo/dizziness, and quality life levels, in patients with bilateral and unilateral peripheral vestibulopathy (total canal paresis).

This study found out that the VOR gain values of the two paradigms were similar in all groups and that the gain values of the two paradigms were significantly correlated especially in the UPV and control groups but with lower SHIMP gains compared to HIMP. We think that the lack of a significant correlation in the BPV group might have resulted from the low number of participants in that group. These results are compatible with the literature [6,12,13]. In the study by MacDougall et al., a difference between the SHIMP and HIMP gain values were obtained in patients with bilateral and unilateral vestibular loss [6]. Because of the appearance of SHIMP saccades usually after the end of the head impulse, MacDougall et al. have suggested that SHIMP facilitates more precise measurement of gains under these conditions by eliminating the majority of catch-up saccades in the sensitive period for the calculation of VOR gains during the head impulse. In this sense, the authors stated that the de-saccade algorithm for the elimination of catch-up saccades used in the measurement of VOR gains might be responsible for the difference between SHIMP and HIMP gains [6]. The study by Rey-Martinez et al. have suggested that the differences between SHIMP and HIMP gain values can be attributed to other mechanisms such as VOR inhibition in addition to the de-saccade algorithm and early saccade mechanism [13]. Additionally, we observed that the saccadic patterns yielded by the HIMP and SHIMP tests were complementary in all groups in our study. In the control group; we did not obtain catch-up saccades in the HIMP test, while we obtained large anti-compensatory saccades in the SHIMP test. In the UPV group; we obtained catch-up saccades when the head turned to the affected side in the HIMP test but not in the SHIMP test. In the BPV group; although we obtained catch-up saccades in the HIMP test, anti-compensatory saccades did not appear in the SHIMP test. Similar results were obtained in the study by MacDougall et al.; who have stated that the emergence of anti-compensatory saccades in the direction of the head movement during the SHIMP test is a sensitive indicator of residual vestibular function [6]. They, therefore, suggested that the detection of residual vestibular function in patients with vestibular loss would be of great clinical importance for vestibular rehabilitation.

In our study; although patients in both BPV and UPV groups had areflexia in the caloric test, we observed VOR gain values of less than 0.8 in only half of the patients and normal values in the remaining patients. Similarly, studies in the literature found vHIT results with normal gain values despite abnormal caloric test results in some patients with chronic peripheral vestibular disorders [14,15]. While vHIT assesses VOR gains with a high-frequency stimulus response, the caloric test assesses VOR gains with a low-frequency stimulus. While irregular afferents encode high-frequency and high-acceleration head movements, regular afferents encode low-frequency and low-acceleration head movements [15,16]. Therefore, the mismatch between these two tests may reflect a variation in central compensation based on the stimulus frequency in case of impaired VOR. It has been suggested that high-frequency VOR has a faster recovery capacity through a different central adaptation mechanism. This suggests that normal results can be obtained in high-frequency vHIT, while low-frequency caloric responses remain abnormal. However; especially in some pathological conditions like Meniere's disease, obtaining normal gain vHIT may not be sufficient to reveal the vestibular asymmetry involving the horizontal semicircular canals [16].

In our study; while the HIMP test showed a low VOR gain in half of the participants of BPV and UPV groups, fHIT revealed abnormal CA percentages in 100% and 90% of the participants of BPV group and UPV groups, respectively. A study by Van Dooren et al. on patients with BPV found bilaterally abnormal fHIT results in 18 out of 23 patients [17]. This result is compatible with those of our study. fHIT selectively stimulates the horizontal semi-circular canal plane during high-frequency passive head movements. Therefore, the percentage of CA is suggested to be low during fHIT because BPV patients can use compensation mechanisms less to improve gaze stabilization [17]. In the UPV patients in our study; while more patients had normal VOR gain in the HIMP test, the abnormal CA percentage in 9 patients in the fHIT test suggested VOR dysfunction in agreement with the study results reported by

Corolla et al. [2]. This finding is not only an indication that the compensation mechanism increases the gain values but also proves that reading the target correctly during the passive head movement is not sufficient.

Considering the ability of patients to understand and complete the test instructions correctly, it has been seen that fHIT, HIMP and SHIMP can be applied and completed in 100% of the patients. Patients have been able to easily match the c optotype on the computer screen with the c optotype on the remote control in fHIT test which is the new paradigm because patients without cognitive problems have been included in the study. Therefore, it is necessary that the cognitive level of patients should not be low for this test. Except for the HIMP and SHIMP paradigms, patients have not felt uncomfortable since they have not used glasses during the test. Moreover, it can give an idea about the improvement of dynamic visual acuity in the vestibular rehabilitation process for the patients who suffer from BPV and UPV, as it can objectively show the deterioration in dynamic visual acuity. For this reason, fHIT can be considered as an objective evaluation method about the effectiveness of vestibular rehabilitation in the future studies.

Although HIMP, SHIMP, and fHIT tests provided evidence of quantitative and functional impairment in VOR in the BPV and UPV groups, we could not find any significant correlations of these results with the vertigo-related self-feeling and quality of life of the patients based on the scores of the VDI-SS and VDI-HQoL scales. Studies about different peripheral vestibular diseases are available in the literature, supporting our findings of the correlation between the objective balance assessments and subjective scale results [18,19]. Herdman et al. have stated that there has been meaningful connection between the presence of vestibular dysfunction and symptom severity, and no correlation has been found between handicap level and objective vestibular findings. On the other hand, the psychological factors such as distress, symptom focusing, embarrassment, avoidance behaviors, and beliefs on negative consequences have been significantly correlated both above and beyond objective vestibular deficits or diagnosis. Therefore, they have concluded that the degree of perceived disability cannot be explained only by taking into account the presence of main structural vestibular deficits. Instead, a combination of disrupted visuo-vestibular perception and psychological characteristics has been used [20]. We also agree with this study and suggest that the lack agreement between the subjective and objective results may result from several variables such as differences in patients' anxiety levels and coping strategies.

The most important limitation of this study is that the size of sample is small. That's why, the obtained test results and comparisons are preliminary result. We aim to increase the case numbers in the future studies so as to detail the obtained results in our study.

To use only caloric test as vestibular test in the criteria of establishing and including BPV and UPV diagnoses is another limitation in our study. It is thought that it will provide more comprehensive assessment in diagnosing vestibulopathy considering the evaluation of vertical canal functions with vertical HIMP and otolith canal functions with VEMP. In the future studies, it is thought that it will be essential to evaluate both vertical and lateral SCC and otolith organ functions with different tests in patients who have vestibulopathy.

Conclusion

The preliminary results show that SHIMP, HIMP and fHIT are complementary each other and able to identify the affected labyrinth and to show residual vestibular function. These tests are thought to be important in the vestibular rehabilitation process. Therefore, routine functional and quantitative evaluation of VOR should be added to clinics to determine residual vestibular function in patients with vestibular loss before vestibular rehabilitation.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Gulce Kirazli http://orcid.org/0000-0001-7108-9987
Sevinc Hepkarsi http://orcid.org/0000-0001-6608-4508
Tayfun Kirazli http://orcid.org/0000-0002-5284-8842

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