Original Article

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기존두부충동검사와 억제두부충동검사 방법의 비교 연구

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Comparison of Suppression Head Impulse and Conventional Head Impulse Test Protocols

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Objectives: The head impulse test paradigm (HIMP) assesses semicircular canal function by measuring compensatory saccades during head movements as an indication of an impaired vestibulo-ocular reflex (VOR). The recently introduced suppression head impulse test paradigm (SHIMP) examines anticompensatory saccades after head movements as a measure of intact VOR. Thus, HIMP measures a decrease in vestibular function, whereas SHIMP measures residual function. We evaluated the effectiveness of SHIMP, compared HIMP and SHIMP results in the same subjects, and examined the relationship between the 2 tests.
Methods: HIMP and SHIMP protocols were performed in 73 patients. The patients were instructed to maintain their gaze on a fixed target for the HIMP, or a moving target for the SHIMP during head impulses. The VOR gain and saccade parameters were compared.
Results: HIMP and SHIMP data were obtained for all ears except in 3 patients. The VOR gain with SHIMP was smaller than for HIMP, but showed significant correlation (r=0.8356, $p<0.001$) and substantial agreement (k=0.79). However, neither the percentage of saccades (appearance of HIMP compensatory saccades and reduction of SHIMP anticompensatory saccades) nor their amplitudes were correlated between the 2 tests.
Conclusions: The HIMP and SHIMP protocols are valuable tools to evaluate VOR during high-velocity head movements. Our results confirm their agreement as measures of VOR gain during head impulses, but also show that the relationship between compensatory and anticompensatory saccades is not straightforward. Thus, care should be taken during clinical interpretation of either protocol.
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Keywords: Head impulse test; Vestibulo-ocular reflex; Vestibular diseases

INTRODUCTION

The vestibulo-ocular reflex (VOR) ensures stable vision by directing the eyes contrary to the head during head movement [1-3]. The gain of VOR is 0.3–0.6 for lower frequencies and closer to 1 at higher frequencies (1–5 kHz). Several laboratory tests have been developed to measure VOR, such as the caloric and rotating chair tests. However, these tests are limited to lower frequency ranges and cannot simulate vestibular stimulation during the 5- to 8-Hz head movement that occurs in daily life. The head impulse test (HIT), a relatively new addition to the vestibular test battery, is a simple and reliable test to assess semicircular canal function during high-velocity head motion [4]. In the HIT, the patient is instructed to fixate on a target on the wall while the clinician turns the patient's head abruptly in the direction of the ear being tested. When vestibular function is normal, eye movements compensate for the head turn, and the patient can maintain a stable gaze on the target. However, when vestibular function is defective, the eyes move with the head, and compensatory saccades occur at the end of the head impulse to restore gaze to the target. Because the compensatory saccades that occur during HITs when ears have a VOR defect are not always visible to the naked eye, video-HIT (vHIT) was developed to provide higher sensitivity to detect covert saccades [5-9]. The original vHIT test, now referred to as the HIT paradigm (HIMP), is a valuable method to detect vestibular hypofunction in patients with various peripheral diseases [7,9-11].

MacDougall et al. [12] developed a new test protocol for the vHIT called the suppression head impulse paradigm (SHIMP). The difference between the SHIMP and the HIMP is that in the latter, a laser dot target is projected from a head-mounted laser source, and the patient is instructed to follow the target as it moves on the wall while the clinician delivers a short, abrupt head impulse. In healthy ears, the VOR drives the eyes in the direction opposite to the direction of head movement during the early phase (first 80 msec), so the patient makes an anticompensatory saccade in the direction of head movement to regain gaze on the target. If the VOR is defective, the eye will follow the laser target during head movement, and there is no need for anticompensatory saccades. To summarize, in healthy ears, the HIMP shows minor compensatory saccades, whereas the SHIMP shows large anticompensatory saccades. In ears with a defective VOR, compensatory saccades occur on the HIMP, and anticompensatory saccades are absent on the SHIMP.

The existence of these 2 vHIT protocols provides a unique opportunity to evaluate vestibular function, as both utilize the VOR, and yet one determines deficiencies, and the other, residual function. There is limited information about the correlation between HIM and SHIMP. One study compared the HIMP and SHIMP in 5 patients with unilateral vestibular loss and 5 patients with bilateral loss, and showed that the presence/absence of the compensatory and anticompensatory saccades was complementary [12]. Another study included normal subjects, patients with acute vestibular loss after vestibular schwannoma surgery, and patients with chronic vestibular loss and no caloric response [13]. However, whether the HIMP and SHIMP tests are complementary under variation in vestibular function, as vestibular functional status is a continuum ranging from absent to a fully intact is not yet known. Our study evaluated the effectiveness of SHIMP by comparing the results of HIMP and SHIMP within the same subjects and examined the correlation between the results of the 2 tests.

MATERIALS AND METHODS

This study included 73 consecutive patients (50 males; mean age, 55.64±16.8 years) who underwent the HIT as a part of vestibular evaluation at an outpatient clinic of Gangnam Severance Hospital from January to April 2017. The study population included patients diagnosed with acute vestibular neuritis (n=5), Meniere disease (n=6), benign paroxysmal positional vertigo (n=11), migrainous vertigo (n=2), cerebellopontine angle tumors (n=13), sudden sensorineural hearing loss with vertigo (n=13), chronic otitis media (n=4), and nonspecific dizziness (n=19). Medical records were reviewed, and clinical diagnoses were based on patient history, physical examinations, and vestibular function tests, excluding the vHIT.

The Institutional Review Board (IRB) of the tertiary referral university hospital approved this study (IRB No. 3-2017-0079).

1. Test Protocols

The HIMP and SHIMP tests were performed by a single experienced technician using a vHIT system for acquisition and analysis of the eye and head movements (ICS impulse ver. 1.0 and OTOsuite vestibular software, GN Otometrics, Taastrup, Denmark). In the HIMP protocol, the subjects were instructed to track a static target at a distance of 1 m in front of them while head impulses were manually delivered by a technician standing behind the subject. The head impulses were repeated at least 10 times toward each side in an unpredictable order, with movement of 5°–10° and peak head velocity of 150–250°/sec. In the SHIMP protocol, the same procedures were followed as in the HIMP protocol, except that the patient was instructed to fixate on a laser dot projected from a head-mounted source and to follow the target as it moved on the wall while the head impulses were delivered. Fig. 1 shows typical recordings in the HIMP and SHIMP tests. In the HIMP test, the eye movement recordings show only few compensatory saccades in a healthy subject, while they are prominent in a patient with impaired VOR. On the other hand, anti-compensatory saccades which are present in a healthy subject are decreased in a patient with imparied VOR. The VOR gain was calculated by comparing the range of head movement with the range of eye movement by measuring the velocity of the head and eye movements over time [7,9]. The overt and covert compensatory saccades during the HIMP and anticompensatory saccades during the SHIMP test were recorded and analyzed [9,12,14]. The mean percentage of saccade responses and the mean amplitude and latency of the saccades were calculated for all head impulses for each individual.

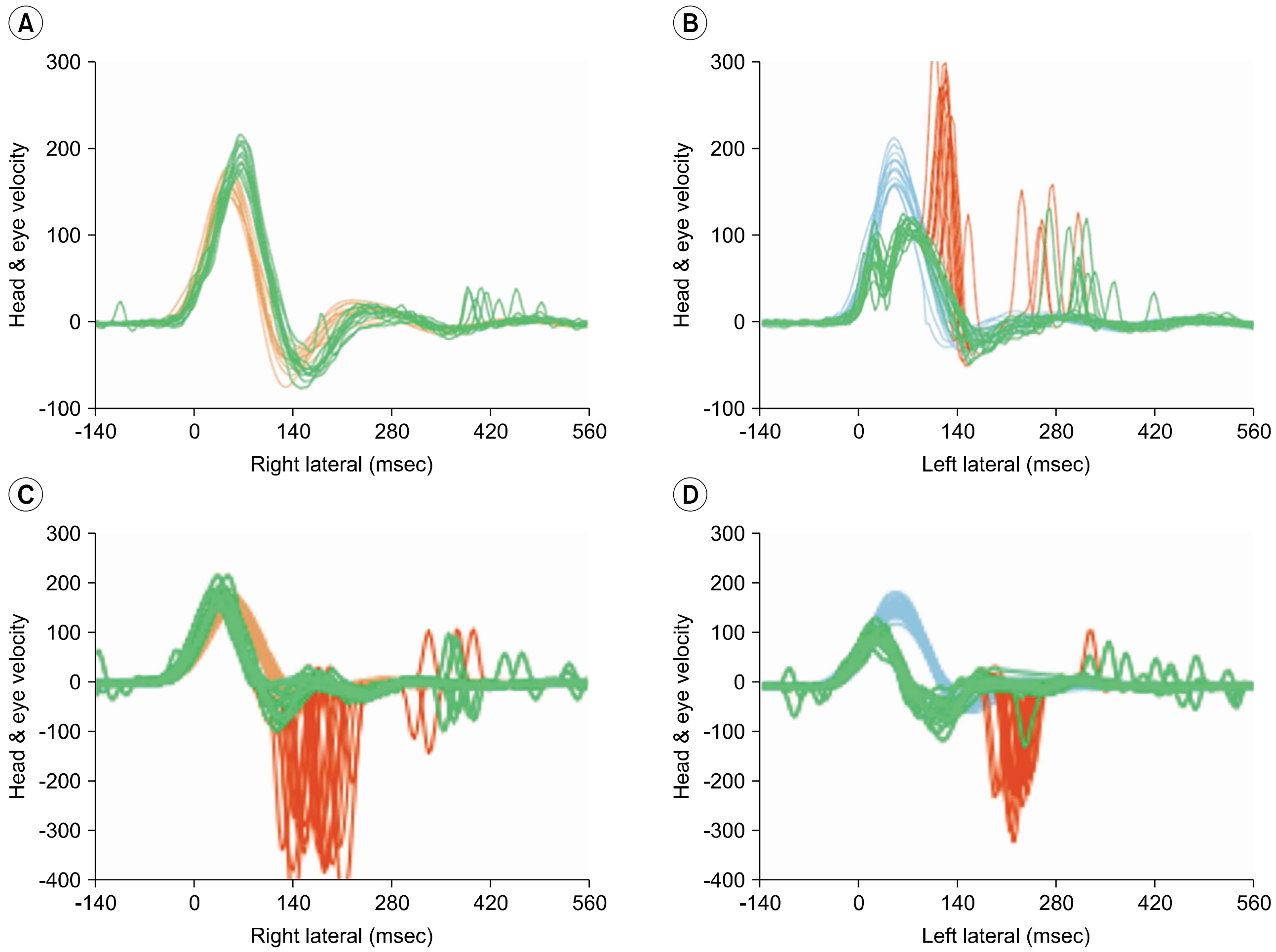

Fig. 1. Representative recordings of the conventional head impulse test paradigm (HIMP) and suppression head impulse test paradigm (SHIMP). In the HIMP protocol, compensatory saccades are absent in a healthy subject (A), but present in a patient with impaired vestibulo-ocular reflex (VOR) (B). In the SHIMP protocol, anticompensatory saccades are present in a healthy subject (C), but decreased in a patient with impaired VOR (D).

2. Statistical Analysis

Statistics were performed using SAS ver. 9.2 (SAS, Inc., Cary, NC, USA) software. Spearman correlation analysis was used to compare the SHIMP and HIMP results; $p<0.05$ was considered significant. The goodness of fit of the linear correlation between the HIMP and SHIMP test results was estimated by the coefficient of determination (r). The Kappa (K) measure of agreement was analyzed to compare percentages of abnormal HIMP and SHIMP test results [15]. Receiver operating characteristic (ROC) statistics were calculated to determine the comparative diagnostic performance of SHIP based on the results of the HIMP.

RESULTS

We obtained results for the HIMP test in all 146 ears of 73 patients, but the SHIMP test results included only 140 ears, as 3 patients could not perform the SHIMP protocol due to discomfort. The mean VOR gain was 0.95±0.16 for the HIMP and 0.87±0.22 for the SHIMP. Compensatory saccades were present in 94 ears (64.38%) on the HIMP protocol; 45 ears showed overt saccades, 8 ears showed covert saccades, and 41 ears showed both overt and covert saccades. Anticompensatory saccades were present in all 140 ears in the SHIMP protocol, and covert saccades were present in 78 ears (55.71%) (Table 1). The saccade amplitudes and latencies are described for reference only; they are not useful for direct comparison because the compensatory saccades and anticompensatory saccades are not direct correlates of each other.

The VOR gain was compared between the HIMP and SHIMP protocols (Table 2), and the results for all 140 ears in which both tests were performed were plotted (Fig. 2A). A significant positive correlation was found between VOR gain with the HIMP and that with the SHIMP test (correlation coefficient=0.8356, $p<0.001$). Cutoff values for VOR gain ≥ 0.8 on the HIMP and VOR gain ≥0.7 on the SHIMP pro-

Table 2. Comparison of VOR gain on the HIMP and SHIMP protocols (n=140)

SHIMP	HIMP		Total
	Gain ≥ 0.8	Gain < 0.8	
Gain ≥ 0.7	131 (97.76)	0 (0)	131 (93.57)
Gain < 0.7	3 (2.24)	6 (100)	9 (6.43)
Total	134 (95.71)	6 (4.29)	140 (100)

VOR, vestibulo-ocular reflex; HIMP, head impulse test; SHIMP, suppression head impulse test.

Table 1. VOR gain and saccade parameters for the HIMP and SHIMP protocols

Variable	HIMP (n=146)	SHIMP (n=140)	p-value
VOR gain	0.95±0.16	0.88±0.17	<0.001
Presence of saccades			<0.001
Compensatory saccades	94 (64.38)	-	
Anticompensatory saccades	-	140 (100)	
Total % of saccade	22.6±29.6	95.64±9.22	<0.001
Saccades types			
Overt saccades only	45 (30.8)	62 (42.5)	0.493
Covert saccades only	8 (5.5)	0 (0)	-
Overt and covert saccades	41 (28.1)	78 (53.4)	0.029
Overt saccade parameters			
No. of ears	86 (58.90)	140 (100)	<0.001
Amplitude (°/sec)	119.30±39.64	298±61.20	<0.001
Latency (msec)	227.05±83.96	204.19±47.57	0.061
Covert saccade parameters			
No. of ears	49 (33.56)	78 (55.71)	0.0003
Amplitude (°/sec)	106.98±56.90	283.57±67.16	<0.001
Latency (msec)	112.15±30.57	118.62±20.03	0.2535

Values are presented as mean±standard deviation or number of ears (%).
VOR, vestibulo-ocular reflex; HIMP, head impulse test; SHIMP, suppression head impulse test.

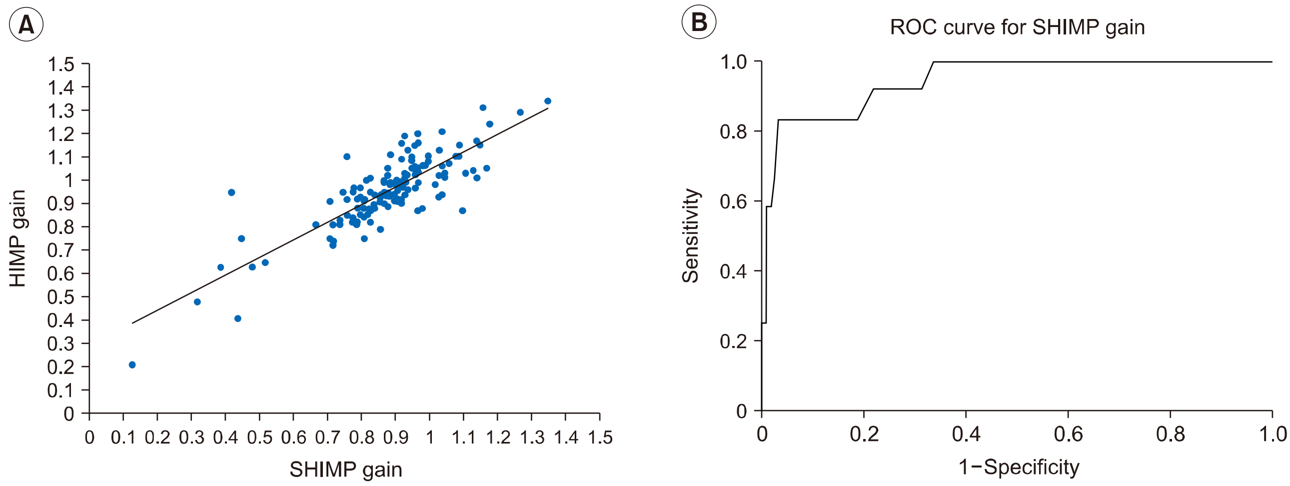

Fig. 2. (A) Scatter plot showing a significant positive correlation between the vestibulo-ocular reflex (VOR) gain on the head impulse test paradigm (HIMP) and suppression head impulse test paradigm (SHIMP) in 140 ears (r=0.8356, $p<0.001$). (B) Receiver operating characteristic (ROC) curve of the VOR gain on the SHIMP plotted against that on the HIMP; the area under the curve was 0.994.

tocols were used, as recommended by the manufacturer. The diagnostic values of the VOR gain on the SHIMP were examined under the assumption that VOR gain on the HIMP is the gold standard (Table 2). The sensitivity, specificity, false positive rate, and false negative rate were 100% (95% confidence interval [CI], 100%–100%), 97.76% (95% CI, 92.26%–100%), 66.67% (95% CI, 35.87%–100%), and 100% (95% CI, 100%–100%), respectively. In addition, the Kappa statistic was used to quantitatively evaluate interobserver agreement between the 2 tests. The Kappa value was 0.79 (95% CI, 0.558–1.000), showing substantial agreement between VOR gain on the HIMP and SHIMP [15]. A ROC curve of VOR gain on the SHIMP is plotted with reference to the VOR gain on the HIMP protocol. The area under the curve (AUC) was 0.994 (95% CI, 0.983–1.000), which supports high predictability of the VOR gain measured by the SHIMP based on the HIMP results (Fig. 2B).

Next, we analyzed the correlation between the saccade parameters in the HIMP and those in the SHIMP protocol. In ears with a defective VOR, compensatory saccades appear in the HIMP, and anticompensatory saccades are reduced in the SHIMP. We hypothesized that the percentage of saccades of the total head impulses observed would be inversely correlated between the HIMP and SHIMP. However, the correlation between the HIMP and SHIMP tests was not significant (r=−0.0313, p=0.7135). Another parameter considered was the amplitude of compensatory saccades in the HIMP and anti-compensatory saccades in the HIMP, which were hypothesized to be inversely correlated. However, this correlation was also not statistically significant (r=−0.2054, p=0.0624).

DISCUSSION

Since the 2 HIT test protocols were designed to assess loss of vestibular function or residual vestibular function by measuring the VOR, we hypothesized that the HIMP and SHIMP would complement each other and that their results would be compatible. Indeed, the HIMP and SHIMP showed very high agreement in determining normal and abnormal sides, with a Kappa value of 0.79, and VOR gain was significantly correlated between the 2 tests. The SHIMP test showed slightly lower VOR gain than did the HIMP test, consistent with a previous report [12]. The VOR is mainly used to stabilize the gaze during abrupt head rotation, and it must be suppressed to change the direction of the gaze during head movement [16,17]. As the SHIMP test requires that the patient follow a moving target created by a laser fixed to the head, this suppression might account for some of the differences in VOR gain. In addition to VOR gain, several parameters can be calculated from either compensatory saccades on the HIMP in ears with a vestibular function deficit or anticompensatory saccades on the SHIMP in ears with intact vestibular function. The velocity of anticompensatory saccades on the SHIMP has been suggested as a new residual vestibular function parameter [13]. However, our results showed no significant correlation between HIMP and SHIMP in either the presence of saccades or their amplitudes. A possible explanation is interference by covert saccades: the presence of a covert saccade may reduce the correlation by reducing the amplitude of subsequent overt saccades. Also, corrective eye movements may be split into 2 or more catch-up saccades, further complicating a direct comparison of saccade amplitudes among patients [18]. Several factors related to test procedures are also important considerations when analyzing VOR gain and saccades [12,19]. Care must be taken to avoid overshooting or "bouncing" at the end of the head impulse, as well as goggle slippage. Furthermore, if the direction of movement or the interval between movements can be predicted, the patient may make anticipatory saccades in the direction of head rotation, further complicating analysis of the saccade.

Given its recent introduction as a novel strategy for vHIT testing, the SHIMP is only beginning to be used in clinics as part of the vestibular test battery [12,13]. The saccade amplitudes of anticompensatory saccades in the SHIMP are generally larger than those of compensatory saccades in the HIMP, so it might be expected that it will be easier to detect changes in anticompensatory saccades and thereby detect an abnormal VOR, with the SHIMP. A possible explanation for our results is that the appearance of compensatory saccades in the HIMP and the reduction of anticompensatory saccades in the SHIMP may not necessarily be reciprocal, and the correlation between them may be nonlinear. For example, when the HIMP shows no abnormal compensatory saccades, the amplitudes of anticompensatory saccades may range from normal to somewhat decreased. Such a discrepancy can also be explained by the 2 tests' differing sensitivity. An important reason for clinical interest in the SHIMP is that it has the potential to detect residual vestibular function during high-velocity head movement. Although the current battery of vestibular function tests includes various methods to assess the VOR, vHIT is unique in using high-velocity head impulse stimuli. The correlation between subjective symptoms of vertigo/oscillopia and documented vestibular dysfunction based on various vestibular tests is not always straightforward [20,21]. Moreover, some studies using either the search coil HIT or the HIMP protocol of the vHIT failed to find a significant association between prolonged vestibular neuritis symptoms and the VOR during high-velocity head movement [22,23]. The question as to whether the SHIMP paradigm is more sensitive in detecting subtle differences in residual function compared to the conventional HIMP remains unanswered, so further studies are warranted. If so the SHIMP is more sensitive, then the ability to identify residual vestibular function in patients with chronic symptoms will provide crucial information to prescribe appropriate customized vestibular rehabilitation methods. To our knowledge, this is the first study to compare results of the HIMP and SHIMP in the same ears of patients with various vestibular disorders. As the new SHIMP protocol is being employed in more vestibular clinics, future studies that include a larger patient population are needed to demonstrate possible advantages and disadvantages of the SHIMP compared to the HIMP.

In summary, VOR gain measured by the HIMP and that by the SHIMP were correlated, but the appearance of the compensatory saccades in the HIMP and the decrease in anticompensatory saccades in the SHIMP test were not correlated. The 2 test protocols can be complementary methods for a comprehensive evaluation of residual vestibular function. However, care should be taken when clinically interpreting either protocol.

중심 단어: 두부충동검사, 전정안반사, 전정질환

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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