# Instantaneous Gain in Video Head Impulse Test: A Reliability Study

Original Investigation

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Abstract

**Objective:** Vestibulo-ocular reflex gain at 40, 60, and 80 ms following the head movement start is calculated as the instantaneous gain. The purpose of this study was to investigate the reliability of instantaneous gain values at 40, 60, and 80 ms with testing and retesting in healthy adults.

**Methods:** The study was conducted with Interacoustics EyeSeeCam vHIT (Interacoustics, Denmark), and 42 healthy adults were evaluated twice at half-hour intervals (test and retest) by the same practitioner. Agreement of mean gain, gain asymmetry, and instantaneous gain was evaluated using a paired samples t-test.

**Results:** Mean age of the participants was 33.62±11.17; 38.1% were male and 61.9% were female. In the degree of the agreement, paired sample correlation (r) between test and retest results of the horizontal semicircular canals was found to be higher than those of the vertical semicircular canals. Moreover, the highest correlation between test and retest for instantaneous gain, calculated for only horizontal semicircular canals, was found at 80 ms on each side (0.791; 0.838, right and left, respectively), while the lowest correlation between these parameters was found between the gain asymmetry values.

**Conclusion:** The video head impulse test used in studies calculates the mean gain in approximately at 60 ms. However, the higher correlation between mean gain values at 80 ms in our findings indicates that gain calculation strategies and techniques for latencies should be discussed. Additionally, the low correlation of vertical semicircular canals for mean gain and gain asymmetry between semicircular canal pairs, which clearly shows that more standard and more reliable methods should be developed.

**Keywords:** Vestibular system, vestibulo ocular reflex, vestibular function tests, video head impulse test, reliability

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## Introduction

The vestibular system is a vital structure made up of simple and complex reflex arcs connecting the semicircular canals to the cognitive regions and is related to various senses. One of the most important reflex arcs, the vestibulo-ocular reflex (VOR), is essential for maintaining a stable gaze during head movement. It consists of a structure that extends from the semicircular canals (SSCs), which are stimulated by the head movement, to the vestibular nuclei, which is a junction point in the brainstem, and to the extra ocular muscles and the oculomotor nuclei (1, 2). VOR is one of the several emerging structures of ocular responses, occurring about 100 seconds after the initiation of the head movement. VOR latency is the shortest time defined for the entire development of VOR in humans, which is 70–80 ms. The gain of the SSCs, the asymmetry between SSC pairs, and the gain-latency relationship of the SSCs are almost all assessed by the video head impulse test (vHIT), which has already been referenced in both clinical practice and in the literature (3, 4).

vHIT is a clinical test that evaluates the dynamic function of six SSCs to detect peripheral vestibular impairments. The clinician performs a high acceleration head rotation in the yawn plane of each SSC while the patient's eyes are fixed on a target. With a compact, light, and high-speed digital camera, vHIT measurements are taken to record eye movements. The camera, which is designed to not slip during head movements, is placed at the supraorbital level tightly around the eyes. Infrared light is cast onto the eyes and the image of the pupilla is projected onto the camera via a mirror. The inertia measuring device, which consists of a two-dimensional gyroscope and a three-dimensional accelerometer mounted on the goggles, measures the head speed (5, 6). Assessment parameters include the gain value for each SSC (main gain: MG), the gain difference between each pair of SSCs (gain asymmetry: GA), and gain values at 40, 60, and 80 ms of horizontal SSCs (instantaneous VOR gain: INSG), which is only a parameter for the device used in this study. Figure 1 shows the above-mentioned parameters on the interface screen. The device estimates the MG of each SSC administered in around 60 ms, indicating that the head movement has reached its maximal point at this time, according to the computation method. Furthermore, unlike the caloric test, the GA between SSCs shows the difference or directional preponderance of gain between horizontal SSC pairs, and gives this information for vertical SSC (7, 8).

vHIT is widely used in vestibular clinics, although despite its benefits, the method's reliability is highly controversial due to various factors such as examiner experience, fitting of goggles, the testing environment, and distance and size of the target point. Furthermore, it should be emphasized that the EyeSeeCam device accepts a gain of about 60 ms during VOR gain and presenting this number as the MG value of horizontal SSCs reduces the test's reliability.

The primary aim of our study was to investigate the reliability of instantaneous gain values at 40, 60 and 80 ms by test and retest method in healthy adults. The secondary aim was to investigate the reliability of the main VOR gain and VOR gain asymmetries of horizontal and vertical SSCs in healthy adults.

## Methods

### Participants

A total of 42 participants (16 males, 26 females) with a mean age of 33.62±11.17 years and a range of 18–55 years were recruited for the study (Table 1). All were healthy adults with no complaints of hearing, no history of any vestibular problems or surgical operations, and no complaints of dizziness or vertigo. The study was carried out at Gazi University's Hearing, Speech, Voice, and Balance Center. Individuals that accepted to participate in the study signed a written consent form. The study was conducted in accordance with the ethical standards of the Helsinki Declaration of 1975. The study was approved by the Human Ethics Committee of Clinical Research of Gazi University Ethics Committee with protocol number 73633 (date: 28/05/2015).

Table1. Demographics

| Participants | | n | % | Age ($\bar{x}$ ± SD) |
|---|---|---|---|---|
| Gender | | 42 | 100.00% | 33.62±11.17 |
| | F | 26 | 61.9% | 33.42±12.30 |
| | M | 16 | 38.1% | 33.94±9.33 |
| | 18–30 | 19 | 45.24% | 23.47±3.48 |
| | 31–45 | 15 | 35.71% | 37.27±4.07 |
| Age groups | 46–55 | 8 | 19.05% | 50.88±3.44 |

n: Number of participants, F: Female, M: Male, $\bar{x}$: Mean, SD: Standard deviation

### Test Procedure

The test was done with the EyeSeeCam vHIT (Interacoustics, Denmark). The device consists of 40-gram goggles with a flexible, bendable frame which is secured to the head with an elastic strap, a mono ocular camera which can be switched between the right and left sides of the glasses. In our study, the camera was placed on the right side of the goggles. There is also a laser mounted at the center of the goggles. A USB 2.0 cable connects the camera to the computer for data transfer. Each participant was asked to sit in an upright position at a distance of 150 cm from a target on the wall. The device was calibrated before each test, according to the manufacturer's guidelines (9).

Testing consisted of three sections: Lateral (Horizontal vHIT: HvHIT) for assessing horizontal SSCs (HSSC); RALP (Right Anterior SSC and Left Posterior SSC); and LARP (Left Anterior SSC and Right Posterior SSC) for assessing vertical SSCs (Vertical vHIT: VvHIT). The examiner stood behind the participant, placed hands on the participant's chin, and delivered randomized (duration and direction) 20 head impulses to the right and left sides (15°) in the plane of the horizontal SSCs (head flexed 30°

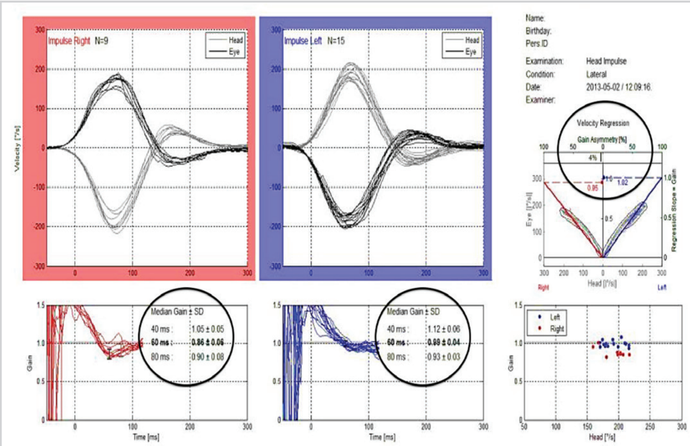


**Figure 1.** Interface of the vHIT software. INSG of the right and left HSSC at 40, 60, and 80 ms are shown by the left and middle black circles, and mean gain and gain asymmetry between the right and left HSSC are shown by the upper right black circle.
vHIT: Video head impulse test, INSG: Instantaneous gain, HSSC: Horizontal semicircular canal

and eyes fixed) in HvHIT. In VvHIT, participant's head was rotated 40–45 degrees to the right of the fixation point and asked to fix their gaze on the fixation point in this position to test the LARP pair of SSC. The left anterior SSC (LA-SSC) is activated in forward diagonal head movements (a head pitch forward), whereas the right posterior SSC (RP-SSC) is activated in backward diagonal head movements (a head pitch backward) (a head pitch back). Similarly, in the RALP test, the participant was asked to fix their gaze on the target while the head was rotated 40–45 degrees to the left. While forward diagonal head movements activate the right anterior SSC (RA-SSC), backward diagonal head movement activate the left posterior SSC (LP-SSC). The same clinician performed a total of 120 head thrusts to each participant, with 20 for each SSC according to the manufacturer's specifications; i.e., head acceleration had to exceed 1,000/sec2, peak angular head velocity had to be reached within the first 150 ms after initiation of head impulse and must exceed 70°/s, and the maximum difference between eye and head velocity before onset of the head impulse does not exceed 20°/s (9). Retesting was done 30 minutes after testing, using the exact same method.

### Statistical Analysis

IBM SPSS version 22 was used to analyze the data (IBM Corp, Armonk, NY, USA). Figures (histograms and probability graphs) and analytical methods (Kolmogorov–Smirnov/Shapiro–Wilk tests) were used to assess the normality of the data distribution. The categorical variables were shown as percentage (%), whereas the continuous variables were shown as mean ($\bar{x}$) and standard deviations (SD). The differences among demographic categories such as gender and age were analyzed using the student's t-test and the one-way ANOVA test. Furthermore, the paired samples t-test was used to analyze whether there was 0.05 significant difference between the test and retest results, and the paired samples correlations value (r) value was computed to investigate the association between repeated tests.

## Results

The mean age of the 42 (38.1% male, %61.9 female) adult participants was 33.62 years. To evaluate the age effect, participants were divided into three age groups of 18–30 years, 31–45 years, and 46–55 years. Demographic details of the participants are given in Table 1.

### Mean Gain and Gain Asymmetry

The values for MG and GA in HvHIT ranged between 0.76–1.20 and 0%–8%, respectively, in test and retest. In VvHIT, ASSC and PSSC MG values were 0.77–1.35 and 0.76–1.29, respectively, and the asymmetry between ASSCs and PSSCs were between 0% and 12%. In HvHIT minimum and maximum INSG values were 0.77–1.87, 0.77–1.45, and 0.64–1.27, respectively, at 40, 60, and 80 ms. The values of the gain parameters of the SSCs in test and retest are shown in Table 2.

**Table 2.** The gain parameter values for SSCs in test and retest

| SSCs MG $\bar{x}$ ± SD | | Test | | Retest | |
|---|---|---|---|---|---|
| | | GA $\bar{x}$ ± SD | MG $\bar{x}$ ± SD | GA $\bar{x}$ ± SD | |
| Horizontal | R-HSSC | 0.96±0.10 | 0.03±0,03 | 0.96±0.09 | 0.03±0.02 |
| | L-HSSC | 1.00±0.10 | | 0.99±0.10 | |
| RALP | RA-SSC | 0.96±0.13 | 0.03±0.02 | 0.95±0.11 | 0.03±0.02 |
| | LP-SSC | 0.95±0.11 | | 0.98±0.11 | |
| LARP | LA-SSC | 1.03±0.16 | 0.03±0.01 | 0.95±0.18 | 0.03±0.02 |
| | RP-SSC | 1.03±0.14 | | 0.97±0.20 | |

GA values were shown in decimal numbers. These numbers can also be presented as the mean (e.g., 0.03=3%).

SSCs: Semicircular canals, MG: Mean gain, GA: Gain asymmetry, RA-SSC: Right anterior semicircular canal, LP-SSC: Left posterior semicircular canals, LA-SSC: Left anterior semicircular canal, RP-SSC: Right posterior semicircular canal, R-HSSC: Right horizontal semicircular canal, L-HSSC: Left horizontal semicircular canal, $\bar{x}$ : Mean, SD: Standard deviation, RALP: Right anterior-left posterior, LARP: Left anterior-right posterior

In the one-way ANOVA test of two sections, there was no statistically significant difference in MG, INSG, and GA values according to age groups ($p>0.05$). Only R-HSSC in MG for the two sections exhibited a statistically significant difference by gender ($p<0.05$) in the student's t-test, although no statistically significant difference was found in others ($p>0.05$).

There was no statistically significant difference between anterior and posterior SSCs and the two sides ($p>0.05$), but there was a statistically significant difference between the VSSCs and the HSSCs ($p<0.05$). The p values of differences between the SSCs as found in the paired sample t-test are shown in Table 3.

**Table 3.** P-values of the student's t-test for the pairwise comparisons of the semicircular canals

| P-value | R-HSSC | L-HSSC | RA-SSC | LP-SSC | LA-SSC | RP-SSC |
|---|---|---|---|---|---|---|
| R-HSSC | 1.000 | 0.212 | 0.001** | 0.008** | 0.018* | 0.002** |
| L-HSSC | 0.212 | 1.000 | 0.006** | 0.001** | 0.003** | 0.001** |
| RA-SSC | 0.001** | 0.006** | 1.000 | 0.531 | 0.233 | 0.401 |
| LP-SSC | 0.008** | 0.001** | 0.531 | 1.000 | 0.226 | 0.301 |
| LA-SSC | 0.018* | 0.003** | 0.233 | 0.226 | 1.000 | 0.839 |
| RP-SSC | 0.002** | 0.001** | 0.401 | 0.301 | 0.839 | 1.000 |

p<0.05:*; p<0.01:**; Statistically significant, R-SSC: Right semicircular canal, L-SSC: Left semicircular canal, RA-SSC: Right anterior semicircular canal, LP-SSC: Left posterior semicircular canals, LA-SSC: Left anterior semicircular canal, RP-SSC: Right posterior semicircular canal, R-HSSC: Right horizontal semicircular canal, L-HSSC: Left horizontal semicircular canal

### Reliability Analysis

For each SSC, t and r correlation values were computed for the reliability analysis of the vHIT parameters between test and retest. t and r values between MG and GA of horizontal and vertical SSCs are detailed in Table 4. According to the results, the r value between horizontal SSC measurements was greater than that between vertical canals, and the agreement of the right horizontal SSC was slightly higher than that of the left horizontal SSC. In the case of GA, all canal pairs with the same plane had low r values. All of the r values were statistically significant (p<0.05).

The INSG relevant to horizontal SSCs is only shown in the gain parameters of the EyeSeeCam device used in this study, but it is not available for vertical SSCs. Figure. 2 illustrates the r value of INSG at 40, 60, and 80 ms of the right and left horizontal SSCs in a scatterplot graph with two variances. According to the graph, the most statistically significant agreement (right, left; r: 0.791; 0.838, respectively) was found at 80 ms (p<0.01). Also, the lowest correlation on each side was found at 40 ms, and the r value at 60 ms was higher than the 40 ms values. Furthermore, there were no statistically significant differences between test and retest measures of any semicircular canals (p>0.05).

## Discussion

vHIT, with its capacity to assess six SSC functions, is a valuable and effective method in the diagnosis, evaluation, and rehabilitation of peripheral vestibular disorders such as labyrinthitis and neuronitis (10, 11). There are many recent studies in the literature that have assessed hearing loss and the effects of medication on the semicircular canals with vHIT (12, 13). VOR is generated by the eye moving at the same speed as the head but in the opposite direction during a head movement to gaze at an object, and the ratio of eye speed to head velocity is called gain and is "1" in healthy people (14, 15). Normative studies, on the other hand, indicate that the gain between 0.7 and 0.8, and anything less is regarded abnormal (16). Having studied only HCCSs in their study, Bansal and Sinha (17) reported MG to be about 0.96. In their review of the literature, Alhabib and Saliba (18) reported the minimum gain value as 0.79 on using EyeSeeCam vHIT system. In our study, MG values for L-HSSC were found as 1.00±0.10 and 0.96±0.10 for R-HSSC. As a result, physiologically normal responses were symmetrical responses and gain values close toone. Although a controversial subject, there are very few normative and

**Table 4.** Paired samples t-test and paired samples correlations value (r)

| Paired sample t-test | | | r | t | p# |
|---|---|---|---|---|---|
| | | R-HSSC | 0.810** | -0.309 | >0.05 |
| **HSSC** | | 0.759** | 1.486 | >0.05 | |
| L-HSSC | | 0.450** | 2.387 | >0.05 | |
| GA | | | | | |
| | | RA-SSC | 0.768** | 1.029 | >0.05 |
| | RALP | LP-SSC | 0.624** | -1.921 | >0.05 |
| | | GA | 0.235* | 0.047 | >0.05 |
| VSSC | | LA-SSC | 0.511** | 1.156 | >0.05 |
| | LARP | RP-SSC | 0.599** | 1.012 | >0.05 |
| | | GA | 0.466** | -0.397 | >0.05 |

p<0.05=*, p<0.01=**, r: Paired samples correlation value, vHIT: Video head impulse test, GA: Gain asymmetry, RA-SSC: Right anterior semicircular canal, LP-SSC: Left posterior semicircular canals, LA-SSC: Left anterior semicircular canal, RP-SSC: Right posterior semicircular canal, RALP: Right anterior-left posterior, LARP: Left anterior-right posterior p#: Paired sample t-test

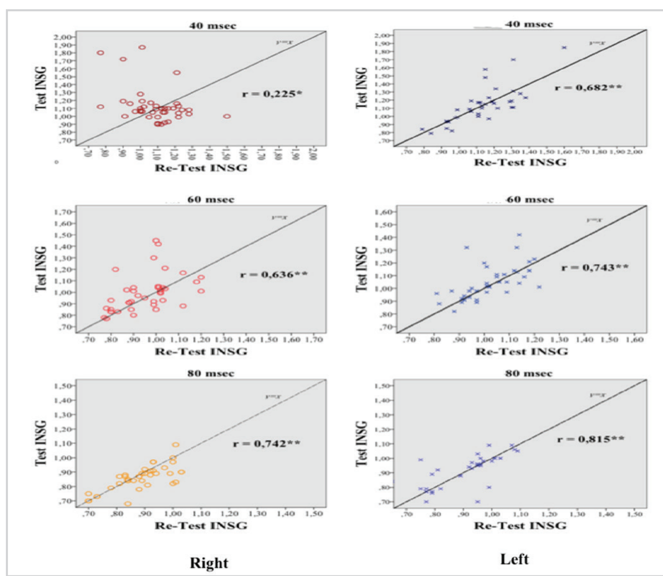


**Figure 2.** For test and retest, scatter plot graphs of INSG values at 40, 60, and 80 ms on the right and left sides. The right side is represented by red circle, and the left side by blue cross.
p<0.05=*, p<0.01=**, r: Paired sample correlation value, INSG: Instantaneous gain

reliability studies on VSSCs. Bansal and Sinha (17) reported the MG of the VSSC to be 0.87 on the average. The average VOR gain for all VSSCs in our study was 0.99, which is consistent with the literature and physiologically similar to our HSSC results.

INSG (instantaneous gain) is a gain parameter available by Interacoustics EyeSeeCam vHIT only for HSSC. There are few studies on this subject, and no reliability studies have been reported. Janky et al. (19) reported MG values of 0.91, 0.97, and 1.01 at 40, 60, and 80 ms, respectively, and indicated that gain increased with time. In contrast to this, INSG values in our study were 1.14, 1.01, and 0.89, respectively. As a result, unlike the referred study, we found that gain had reduced as latency increased. Mossman et al. (20) only investigating the VOR values at 60 and 80 ms, found the highest and lowest gain values to be 0.76–1.18 and 0.65–1.17, respectively. In our study these values were 0.77–1.45 and 0.70–1.25, respectively.

There are numerous studies that compared the caloric test in healthy individuals and patients, but how vHIT should be used and interpreted are still a matter of discussion. Some studies focus on the benefits of the caloric test, while others highlight the benefits of vHIT (21-24). According to these studies, the most essential advantage of vHIT is the rapid stimulation of the six semicircular canals, yet the caloric test has a greater reliability than vHIT. Singh et al. (25) reported a significant relation in intraclass correlation coefficient values (ICC) of 0.76, 0.86, and 0.77 for HSSCs, A-SSCs, and P-SSCs, respectively. Macdougall et al. (26) found a statistically significant correlation between the scleral coil measuring method and VvHIT in their patient group, with r=0.98. Although there was a statistically significant and strong agreement for HSSCs on the right and left sides, r=0.810 and 0.759, respectively (p<0.01), statistically significant correlation was found for VSSCs, RA, LP, LA, and RP-SSC, respectively, r=0.718, 0.624, 0.511, 0.599. The most crucial reason why VSSC demonstrated a worse correlation than HSSCs was assumed to be related to the practitioner's reliability and patient compliance during the test. According to Abrahamsen et al. (27), the effects of the inter-examiner were greater than the effects of the intra-examiner in one test system, but the opposite was true in another. Another factor which contributed to the difference in the correlation was the difficulty of holding the goggles in place during head movement. Suh et al. (28) reported that, the tightness of the strap of the googles affected VOR gains, therefore the strap should be tightened to at least 45 cm/Hg. In our study, our approach was to make sure that the goggles were positioned comfortably on the participants' heads since the device for measuring tightness was not included in the test equipment.

Finally, we believe that using the head movement technique in horizontal semicircular canals is easier than in vertical semicircular canals, and that the head movement angle may be easily altered.

As previously stated, 40, 60, and 80 ms gain values for HSSCs are calculated only on EyeSeeCam while INSG-related head movement continues. The value is computed by generating a regression of the head and eye speeds in these ms, and the device outputs a gain of about 60 ms as MG. There are only a few reports on this topic in the literature. Jacobsen et al. (29) compared the instantaneous gain values to the average gain value and evaluated its repeatability in a study with 60 patients without a vestibular history. According to the authors, the standard deviation of the VOR gain reported at 40 ms was significant, and while it was statistically different from the average gain value, there was no statistical difference at 60 and 80 ms. This study differs from ours in terms of statistical analysis and findings. We found that the correlation findings at 80 ms were slightly better than those at 40 and 60 ms, as well as the HSSC MG correlation findings (Table 4 and Figure 2). As a result, the reliability of the MG parameter produced by this device at 60 ms is controversial.

The caloric test, like the vHIT, calculates asymmetry between pairs of HSSCs. vHIT, on the other hand, calculates GA between pairs of VSSCs in addition to HSSCs.

According to Yang et al. (30), the mean GA of HSSCs was about 2.4, with a minimum value of zero and a maximum value of seven. The mean GA for HSSCs in our study was around 3% [minimum (min)–maximum (max): 0%–8%], while the mean GA for VSSCs was three (min-max: 0%–12%). As a result, it is clear that these findings are consistent with the literature. There are only few studies on the GA values of vertical SSC pairs and the GA reliability of all SSC pairs. Our study revealed that the correlation between GA values was lower than the correlation between MG values (Table 4). We believe that this could be due to the result of the MG-affecting aspects mentioned before. MG can also be affected by the distance and the size of the target. According to Judge et al. (31), gain increases as the target size increases, and it declines as the target distance decreases. In our study, measurements were taken using the manufacturer's recommended distance (150 cm) and target point types.

We believe that our study will contribute to the literature on this topic as GA is a diagnostic criterion, especially in patients with unilateral VOR insufficiency, and important in rehabilitation follow-up of patients with vestibular dysfunction.

Vestibular hypofunction can be revealed by corrective saccades (11). vHIT can be used to measure the frequency, amplitude, and latency of saccades, and several studies have been conducted on this topic. In their study with 25 participants who had undergone cochlear implant surgery, Korsager et al. (32), using EyeSeeCam vHIT, concluded that the occurrence of saccades, not the gain value, should be used to evaluate vHIT outcomes. Janky et al. (33) reported that corrective saccade frequency analysis provided good diagnosis accuracy in 49 patients with bilateral and unilateral vestibular abnormalities, with an 81.9% agreement rate on repeated measures. The reliability of VOR gains was assessed in healthy adults at three separate times (40, 60, and 80 ms) in our study, with varying accuracy findings at each period. We expect that studying the diagnostic accuracy of instantaneous gain values in various vestibular diseases will make a substantial contribution to the literature.

There is clear evidence that the degradation of primary efferent nerves and vestibular cells is associated with ageing. Each semicircular canal in a healthy young adult has a significant number of receptor cells. However, it has been demonstrated that the number of these receptor cells reduce with age (34). McGarvie et al. (15) and Mossman et al. (20) found that MG decreased with age in the function of horizontal semicircular canals, but that this decrease was not statistically significant. To evaluate the effect of age on VOR gain, we divided the participants into three age groups (Table 1). No statistically significant differences were found among these three age groups.

## Conclusion

In our study we examined INSG and gain values of VOR. In the literature, there are just a few studies on this topic. The gain at 80 ms was significantly higher than the gains at 40 and 60 ms. Because the device accepts the main VOR gain value at 40 and 60 ms, measurement inconsistency is likely. Furthermore, in terms of agreement, VOR gain values in vertical canals were lower than horizontal canals in our study. The agreement between the RALP and LARP test phases, which are evaluated in the vertical canals, is a subject of controversy. Different strategies should be devised to improve the vertical evaluation's reliability. Finally, the results of the presented study can be used as a norm in vestibular clinics and studies.

**Ethics Committee Approval:** The procedure was approved by the Human Ethics Gazi University Committee of Clinical Research (protocol number: 73633, date: 28/05/2015).

**Informed Consent:** Individuals that accepted to participate in the study signed a written consent form.

**Peer-review:** Externally peer-reviewed.

**Authorship Contributions**

Concept: B.K., H.T., B.G., Design: B.K., H.T., B.G., Supervision: H.T., B.G., Data Collection and/or Processing: B.K., Analysis and/or Interpretation: B.K., H.T., B.G., S.A., Literature Search: B.K., S.A., Writing: B.K., Critical Review: B.G., S.A.

**Conflict of Interest:** The authors have no conflicts of interest to declare.

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**Main Points**

- We report the findings of the study on the reliability of instantaneous gain.
- The gain at 80 milliseconds was found to be more reliable than the gains at 40 and 60 milliseconds.
- The gain asymmetry between semisircular canal pairs and the normative values of the gain for all semicircular canals were reported.
- VOR gains in horizontal semicircular canals were shown to be more reliable than VOR gains in vertical semicircular canals.
- The findings indicate that standard vHIT implementation methods should be developed.

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