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Original Article

Test-Retest Reliability, Effects of Age and Comparison of Horizontal 2 Semicircular Canals Gain Values between Head Impulse and Suppression Head Impulse Paradigms

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BACKGROUND: This study investigates the test-retest reliability, aging effects, and differences in horizontal semicircular canals gain values between the head impulse paradigm and suppression head impulse paradigm.

METHODS: Sixty healthy adult subjects aged 22-76-year-old (mean ± standard deviation = 47.27 ± 18.29) participated in the head impulse paradigm and suppression head impulse paradigm using the video head impulse test. The Head impulse paradigm was used to assess all 6 semicircular canals, while suppression head impulse paradigm measured only the horizontal canals. Twenty subjects aged 22-40-year-old (25.25 ± 4.9) underwent a second session for the test-retest reliability.

RESULTS: There were good test-retest reliability for both measures (right horizontal head impulse paradigm, intraclass correlation coefficient = 0.80; left horizontal head impulse paradigm, intraclass correlation coefficient = 0.77; right anterior head impulse paradigm, intraclass correlation coefficient = 0.86; left anterior head impulse paradigm, intraclass correlation coefficient = 0.78; right posterior head impulse paradigm, intraclass correlation coefficient = 0.78; left posterior head impulse paradigm, intraclass correlation coefficient = 0.75; right horizontal suppression head impulse paradigm, intraclass correlation coefficient = 0.76; left horizontal suppression head impulse paradigm, intraclass correlation coefficient = 0.79). The test-retest reliability for suppression head impulse paradigmanti-compensatory saccade latency and amplitude were moderate (right latency, intraclass correlation coefficient = 0.61; left latency, intraclass correlation coefficient = 0.69; right amplitude, intraclass correlation coefficient = 0.69; left amplitude, intraclass correlation coefficient = 0.58). There were no significant effects of age on head impulse paradigm and suppression head impulse paradigm vestibulo-ocular reflex gain values and suppression head impulse paradigmsaccade latency. However, the saccade amplitude became smaller with increasing age, $P < .001$. The horizontal suppression head impulse paradigm vestibulo-ocular reflex gain values were significantly lower than the head impulse paradigm for both sides (right, $P = .004$; left, $P = .004$).

CONCLUSION: There was good test-retest reliability for both measures, and the gain values stabilized with age. However, suppression head impulse paradigm anti-compensatory saccade latency and amplitude had lower test-retest reliability than the gain. The suppression head impulse paradigm vestibulo-ocular reflex gain was lower than the head impulse paradigm and its anti-compensatory saccade amplitude reduced with increasing age.

KEYWORDS: Head impulse paradigm, suppression head impulse paradigm, vestibulo-ocular reflex, aging, test-retest

INTRODUCTION

The video head impulse test (vHIT) has been widely used as a clinical test to assess the semicircular canals (SCCs) function. The vHIT is delivered in small amplitudes but high-velocity head impulses in the directions of SCCs pair of coplanar.[1-3] The right horizontal

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corresponded to the left horizontal, right anterior to the left posterior (RALP), and left anterior to the right posterior (LARP). This allows accurate measurements of each SCC. Healthy subjects were reported to have vestibulo-ocular reflex (VOR) gain of around 1.0, where the head turned is at a similar pace to the VOR.[1,4,5] In the vestibular loss cases, the eyes generate inadequate slow-phase movements; therefore, saccades will occur for the eyes to refixate to the target image.[6] Consequently, the gain is usually significantly lower than 1.0 due to the deficient VOR.[1,4,5]

The suppression head impulse paradigm (SHIMP) was recently introduced as a complementary test to the original vHIT head impulse paradigm, also known as HIMP.[3,5] Unlike HIMP which could assess vertical canals, SHIMP could only test horizontal canals.[7] This could be during the RALP or LARP testing, the head will be turned 30° to the left or right, and the goggle projected the target light according to this head movement. Suppression head impulse paradigm is difficult to measure for the vertical canals as the test requires the subject to maintain the gaze straight ahead during the testing while the target light is projected to a different position with head movement. Both HIMP and SHIMP have different approaches to identifying VOR integrity for the horizontal canals. While HIMP measures the ability of the eye to focus on an earth-fixed target during head movement, the SHIMP assesses the ability of the eye to track a head-impulse-driven target.[3-5] Healthy individuals usually have high HIMP VOR gain, that is, around 1.0, with a few or no compensatory saccades. While for SHIMP, healthy individuals tend to have slightly lower VOR gain than HIMP, but with large SHIMP anti-compensatory saccades.[3,8] The SHIMP induces large anti-compensatory saccades in the direction of head impulse as the eyes drive-off target upon head turn from the onset to re-acquire the moving image.[5,9] For a vestibular loss patient, both HIMP and SHIMP VOR gain values are reduced significantly on the affected side, with the presence of HIMP saccades to correct for eye movement and only a few or no anti-compensatory saccades on SHIMP.[3,8] Among the vestibular loss patients who elicited anti-compensatory saccades on SHIMP, the mean peak saccade velocities were smaller with longer latencies than in healthy adults.[8] These findings indicate that, while HIMP VOR gain and saccades are used to identify vestibular loss, the SHIMP measurements such as VOR gain values, latencies, and amplitude[3] or peak saccade velocities[8] can be useful in assessing residual vestibular function. Studies have shown that anti-compensatory saccades are crucial in identifying vestibular compensation among patients with bilateral vestibular loss.[3,8] Identifying anti-compensatory saccades are useful to determine appropriate vestibular rehabilitation by understanding the learning strategy used to maintain gaze for vestibular loss patients.[9] A recent study reported that SHIMP is not only useful to assess residual vestibular function but could be valuable than HIMP to assess the dynamic integrity of horizontal SCC, especially among patients with acute vestibular syndrome.[10] The SHIMP is not influenced by the covert saccades and provides information on vestibulo–saccadic interaction of peripheral vestibular loss.[10]

Previous studies have revealed good test-retest agreements of HIMP VOR gain measures.[11,12] However, little is known about the test-retest reliability of SHIMP. Several studies also reported variability in VOR gain values as a function of age among healthy individuals. The vHIT VOR gain is stabilized and not affected by age, for at least up to 60 years old.[13,14] Other studies found that the VOR gain values did not reduce with age for up to 70 years old,[15,16] 79 years old,[17] or 89 years old.[18] Mossman et al[19] reported that the VOR gain was reduced by 0.012 and 0.017 in the increasing age band at 80 ms and 60 ms, respectively. The possibilities of reduced VOR gain with increasing age could be due to the vestibular degeneration in the aging population.[17]

Given the potential application of SHIMP as a complementary measure of vestibular function to HIMP, it is essential to identify the reliability of the test to be used in the clinical setting. To the best of our knowledge, there is no prior study on the test-retest reliability, effects of age, and differences in the VOR gain values between HIMP and SHIMP. Therefore, this study aims to explore and establish the test-retest reliability and age effect on HIMP and SHIMP. Quantification of effects of test-retest reliability and effects of age were determined for HIMP for all 6 SCCs and SHIMP for horizontal SCCs. Comparisons of VOR gain values were analyzed between HIMP and SHIMP horizontal SCCs.

METHODS

Sixty healthy subjects, aged between 22 and 76 years old, mean ± standard deviation (SD) = 47.27 ± 18.29 years, participated in the study. Of the 60 patients, 20 were males and 40 were females. The control group was divided into 4 groups, aged between 20-39 years old (n = 20, 33%), 40-49 years old (n = 9, 15%), 50-59 years old (n = 10, 17 %), 60-69 years old (n = 16, 27%), and 70 years old and above (n = 5, 8%). Their data was used for age-related HIMP and SHIMP analyses.

Twenty of the subjects (3 males and 17 females), aged 22-40 years old (25.25 ± 4.9), who participated in the study underwent the second testing session between 2 and 21 days from their first testing session with the same tester. Their data from the first and second testing sessions were used to identify the horizontal HIMP and SHIMP test-retest reliability analysis. All participants selected had no history of otological, neurological, or vestibular diseases. Written consents were obtained from all subjects. Our institutional ethics review board approved the study.

Video Head Impulse Testing

A portable vHIT device (GN Otometrics, ICS Impulse, USA) was used to assess the VOR function of HIMP and SHIMP as previously described.[9,12,20,21] The vHIT consists of a pair of light-weight video goggles and an infra-red video camera on the right side of the frame, equipped with a head-mounted red-laser beam. The goggle was secured on the subject's head using an adjustable strap to avoid slippage during head impulses. The subjects were instructed to sit facing an eye-level central target, placed 1 m ahead. Before testing, calibration was performed by instructing the subjects to maintain their gaze at a visual laser target projected from the goggle.

In HIMP testing, rapid and unpredictable head impulses were performed randomly to the left and right sides at least 20 times on each side to measure the VOR for lateral SCCs. A tester stood behind the subject and delivered the head impulse by holding the subject's head. The amplitude of head thrusts was performed between 10° and 20°, with the head velocity of 100°-250°/s and acceleration between 1000° and 2500°/s². A similar up and down head thrusts movement approach was also performed to measure the RALP and

LARP canal planes. The subject's head was turned 30° to the left (to test RALP) and 30° to the right (to test LARP).

A similar head thrust approach was utilized for SHIMP. For SHIMP, subjects were asked to follow a laser-moving target that moved together with the head impulses rather than focusing on the central target. At least 20 impulses to the left and right were delivered in random orders. The SHIMP allows for the calculation of VOR gain and saccade measurements. Trials with blinks and outliers were removed from the study based on the expected response of the eye velocity envelope.[1,3]

The VOR gain measurements were analyzed according to the manufacturer's specification[22] and as previously described.[3] The HIMP and SHIMP VOR gain was analyzed as the eye velocity divided by head velocity,[5] and VOR gain asymmetry was analyzed using the following formula:

Gain Asymmetry: (Right ear gain − left ear gain)/(right ear gain + left ear gain)

The SHIMP anti-compensatory peak saccade amplitude was analyzed as the saccades averages to a number of trials.[3] The same analysis was performed for peak saccade latencies.

Statistical Analysis

Statistical analyses were performed using IBM SPSS v.24 software (IBM SPSS Corp.; Armonk, NY, USA). The Shapiro-Wilk test was used to check for data normalcy. The first part of the study involves the identification of test-retest reliability of both HIMP and SHIMP testing. Test-retest reliability was assessed using the intraclass correlation coefficient (ICC) analyzed using 2-way random effects and absolute agreement. The ICCs of less than 0.5 were classified as poor, between 0.5 and 0.75 as moderate, 0.75 and 0.9 as good and above 9.0 as excellent.[23] The second part of the study identified the effects of age on HIMP, and SHIMP VOR gain values, SHIMP anti-compensatory saccade latency, and amplitude measurements. A mixed-factor ANOVA was performed with side (right and left ears) within-group and age groups as between-group factors. Finally, a paired *t*-test was used to identify differences between HIMP and SHIMP VOR gain values. *P* values of less than .05 were interpreted as statistically significant.

RESULTS

Test-Retest Reliability

Figure 1 shows the ICC values for both HIMP and SHIMP mean VOR gain in different SCCs. Regarding the HIMP testing, ICC values indicate good reliability (ICC > 0.7) for all horizontal, anterior, and posterior canals on both sides. The SHIMP ICCs also revealed good reliability for both right (ICC = 0.76) and left sides (ICC = 0.79), comparable to the horizontal HIMP testing. However, the reliability was moderate for SHIMP anti-compensatory saccade latency (right ICC = 0.61; left ICC = 0.69) and amplitude (right ICC = 0.69; left ICC = 0.58) as shown in Figures 2 and 3, respectively. In general, the test-retest reliability was good for HIMP and SHIMP VOR gain values but slightly lower for the SHIMP anti-compensatory saccade latency and amplitude.

Age-Related Trends for HIMP and SHIMP VOR Gain Values

Table 1 shows the mean VOR gain values for both HIMP and SHIMP. The mean VOR gain for HIMP horizontal SCCs was approximately 1.0 but slightly lower for vertical canals. For the horizontal SCCs, the mean cumulative HIMP VOR gain values were higher than the SHIMP for both the right (mean gain difference 0.04 ± 0.11, $P < .004$) and left side (mean gain difference 0.03 ± 0.08, $P < .004$).

Mixed factor ANOVA (Table 2) revealed significant effects on the testing side, in which the VOR gain values were higher on the right than on the left side for the HIMP horizontal SCCs ($P < .001$) and SHIMP horizontal SCCs ($P = .001$), but not for anterior SCCs ($P = .376$) and posterior SCCs ($P = .212$). There were no significant effects of age for HIMP and SHIMP VOR gain values for each SCC tested. There were also no significant interactions between side and age for HIMP horizontal,

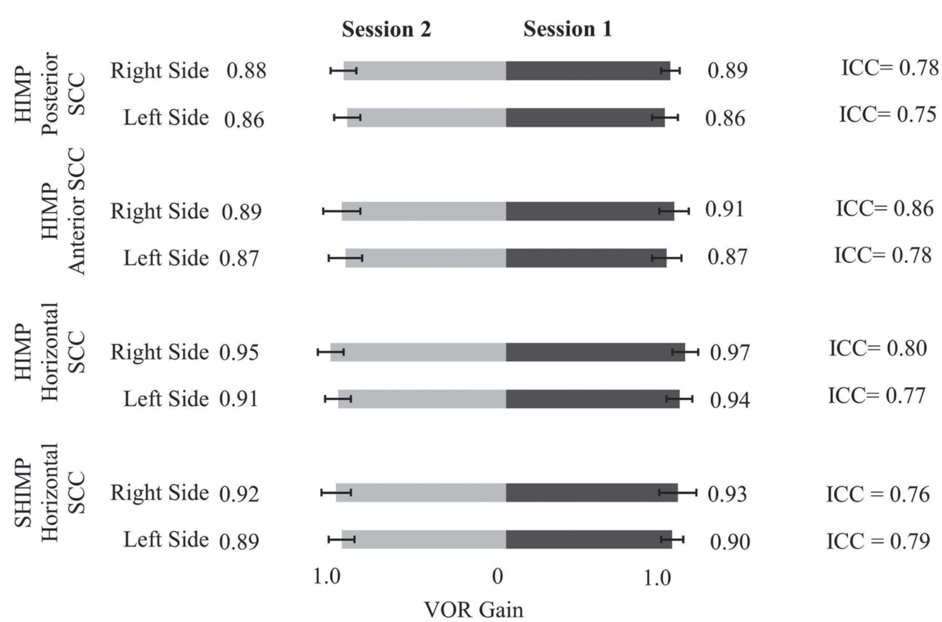

Figure 1. The HIMP and SHIMP mean VOR gain values for sessions 1 and 2. The error bars represent the standard deviation values.

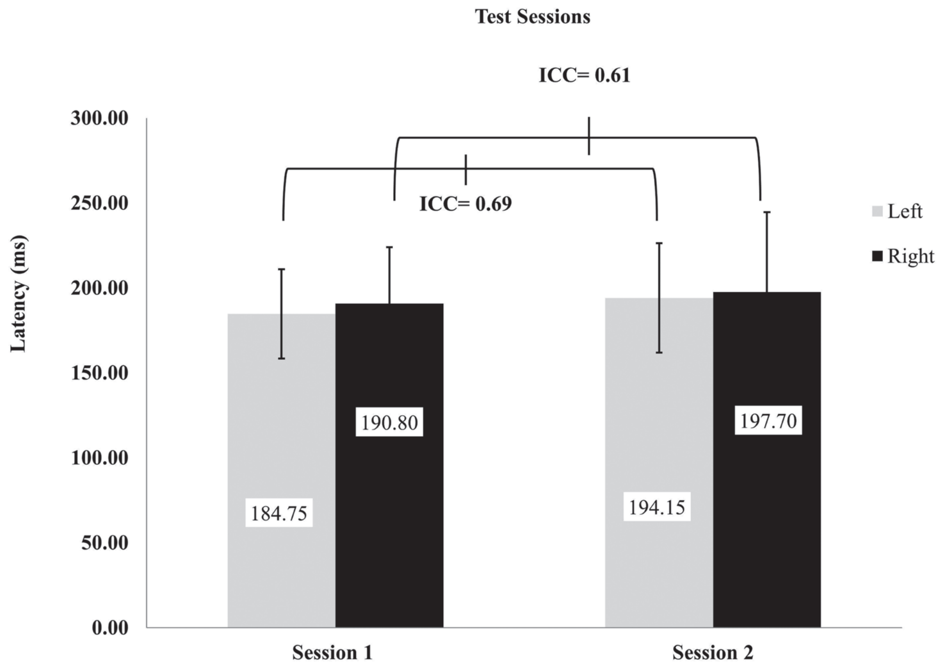

Figure 2. SHIMP anti-compensatory saccade latencies for sessions 1 and 2. The error bars represent the standard deviation values.

anterior, posterior SCCs, and SHIMP horizontal SCCs. These indicate that the HIMP and SHIMP VOR gain values were stable with increasing age, for at least until the 70s.

Age-Related Trends for SHIMP Anti-compensatory Saccade Amplitude and Latency

All subjects in this study elicited anti-compensatory saccades for SHIMP, but only a few absent saccades for HIMP were shown. Figure 4 shows an example of the two paradigms. Table 3 shows the anti-compensatory saccade latency and amplitude values for SHIMP. There were no significant effects of anti-compensatory saccade latency on age, or testing side, or interaction between the testing side and age (Table 4). For the anti-compensatory saccade amplitude, there was a significant main effect of age, $P < .001$. There was no significant effect of testing side or interaction between side and age for the saccade amplitude. The anti-compensatory saccade amplitude for the age group 70 years old and above was significantly smaller than the younger age groups of 20-39 years old, $P < .001$, 30-39 years old, $P = .031$, 40-49 years old, $P < .001$, and 50-59 years old, $P < .001$, suggesting that the saccade amplitude reduced after the 70s.

DISCUSSION

This study identifies the test-retest reliability and effects of age on HIMP for all 6 SCCs and SHIMP horizontal SCC. Gain values were

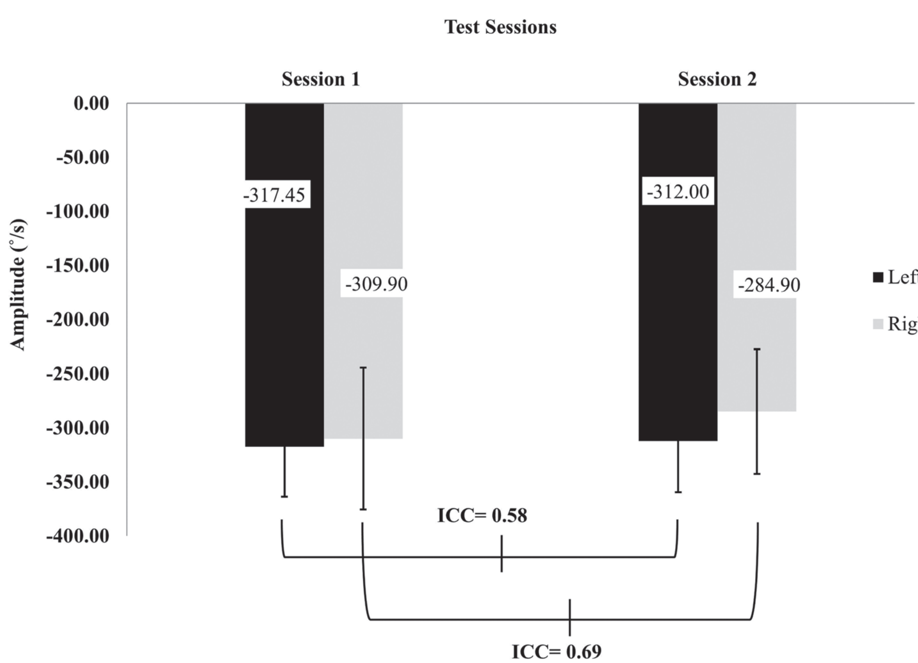

Figure 3. SHIMP anti-compensatory saccade amplitude for test sessions 1 and 2. The error bars represent the standard deviation values.

Table 1. Mean ± Standard Deviations (SDs) of VOR Gain and Asymmetry Ratio Values of HIMP Horizontal and Vertical Semicircular Canals (SCCs) and SHIMP Horizontal SCCs for both Right and Left Ears in Each Age Group

		HIMP, Mean ± SD		Horizontal SHIMP, Mean ± SD	
Age Group (Years)	**Side**	**Horizontal**	**Anterior**	**Posterior**	**Horizontal**
20-39	Right	0.96 ± 0.08	0.91 ± 0.09	0.88 ± 0.06	0.93 ± 0.06
	Left	0.93 ± 0.08	0.87 ± 0.09	0.86 ± 0.07	0.90 ± 0.07
	Asymmetry	0.02 ± 0.02	0.02 ± 0.05	0.01 ± 0.04	0.02 ± 0.03
40-49	Right	1.01 ± 0.10	0.88 ± 0.09	0.87 ± 0.10	0.94 ± 0.15
	Left	0.98 ± 0.11	0.90 ± 0.07	0.84 ± 0.08	0.92 ± 0.08
	Asymmetry	0.01 ± 0.05	−0.01 ± 0.08	0.02 ± 0.07	0.01 ± 0.05
50-59	Right	0.99 ± 0.05	0.88 ± 0.08	0.86 ± 0.09	0.92 ± 0.06
	Left	0.96 ± 0.06	0.86 ± 0.09	0.84 ± 0.06	0.92 ± 0.06
	Asymmetry	0.01 ± 0.03	0.01 ± 0.05	0.01 ± 0.06	0.00 ± 0.01
60-69	Right	1.02 ± 0.07	0.94 ± 1.0	0.88 ± 0.11	0.98 ± 0.07
	Left	0.96 ± 0.06	0.92 ± 0.11	0.88 ± 0.11	0.94 ± 0.09
	Asymmetry	0.03 ± 0.02	0.01 ± 0.07	0.00 ± 0.07	0.02 ± 0.02
≥70	Right	0.98 ± 0.15	0.82 ± 0.10	0.83 ± 0.04	0.99 ± 0.31
	Left	0.92 ± 0.11	0.81 ± 0.08	0.81 ± 0.07	0.94 ± 0.22
	Asymmetry	0.03 ± 0.05	0.01 ± 0.09	0.01 ± 0.06	0.02 ± 0.04
Average	Right	0.99 ± 0.09	0.90 ± 0.10	0.87 ± 0.08	0.95 ± 0.11
	Left	0.95 ± 0.08	0.88 ± 0.09	0.86 ± 0.08	0.92 ± 0.09
	Asymmetry	0.02 ± 0.03	0.01 ± 0.06	0.01 ± 0.006	0.02 ± 0.03

compared between HIMP and SHIMP for horizontal SCCs. The HIMP measures the ability of the subjects to maintain a gaze at a fixed target during head movements. In SHIMP testing, where the target moves with the head impulse, an anti-compensatory saccade was elicited in the direction of head movement to re-visualize a moving target. In all participating subjects, SHIMP and HIMP resulted in a reversed saccadic pattern: during HIMP, healthy controls elicited only a few positive or no catch-up saccades, while during SHIMP, they elicited large negative saccades back to the head-fixed target after the end of the head impulses. Previous studies suggested that both HIMP and SHIMP can be valuable to assess the dynamic integrity of SCCs. While HIMP can identify vestibular loss, the SHIMP can be helpful to identify residual vestibular function.[3,8]

Table 2. Mixed Factor ANOVA of HIMP Horizontal, Anterior, and Posterior Semicircular Canals (SCCs) and SHIMP Horizontal SCCs VOR Gain Values Based on the Sides (Right and Left) and Sge Groups

SCC	F	*df*	*P*
HIMP Horizontal SCC			
Side	32.797	1	<.001**
Age	1.275	4	.291
Side × Age	1.070	4	.380
HIMP Anterior SCC			
Side	0.797	1	.376
Age	2.477	4	.055
Side × Age	0.553	4	.698
HIMP Posterior SCC			
Side	1.594	1	.212
Age	0.902	4	.469
Side × Age	0.297	4	.879
SHIMP Horizontal SCC			
Side	12.39	1	.001**
Age	0.728	4	.577
Side × Age	0.694	4	.599

**Significant at the level of .05.

The first objective of this study is to identify the test-retest reliability for both HIMP and SHIMP measurements. The findings indicate that the HIMP VOR gain values were reliable, as reported by previous studies.[11,12,24] The present study also found that the SHIMP VOR gain values had good test-retest reliability. However, both anti-compensatory saccade latency and amplitude had moderate test-retest reliability. The variability of SHIMP anti-compensatory saccade latency and amplitude in this study could also be contributed by the effects of target distances and head impulse velocity between testing. Kim and Kim[16] also reported that the target distance, head velocity, and head impulse direction could also influence the VOR gain. Nevertheless, the results of this study suggest that the SHIMP VOR gain is a reliable test to be used along with HIMP in the clinical setting.

The HIMP mean VOR gain values for horizontal SCCs concur with previous studies that reported average gain to be around 1.0.[12,13,15] with a slightly lower gain for vertical SCCs.[12,18] There was a significant difference in VOR gain between the right and left sides in the present study, with the VOR gain on the right side higher than the gain on the left side for both HIMP and SHIMP horizontal SCCs. This finding is consistent with previous findings that reported higher VOR gain mainly

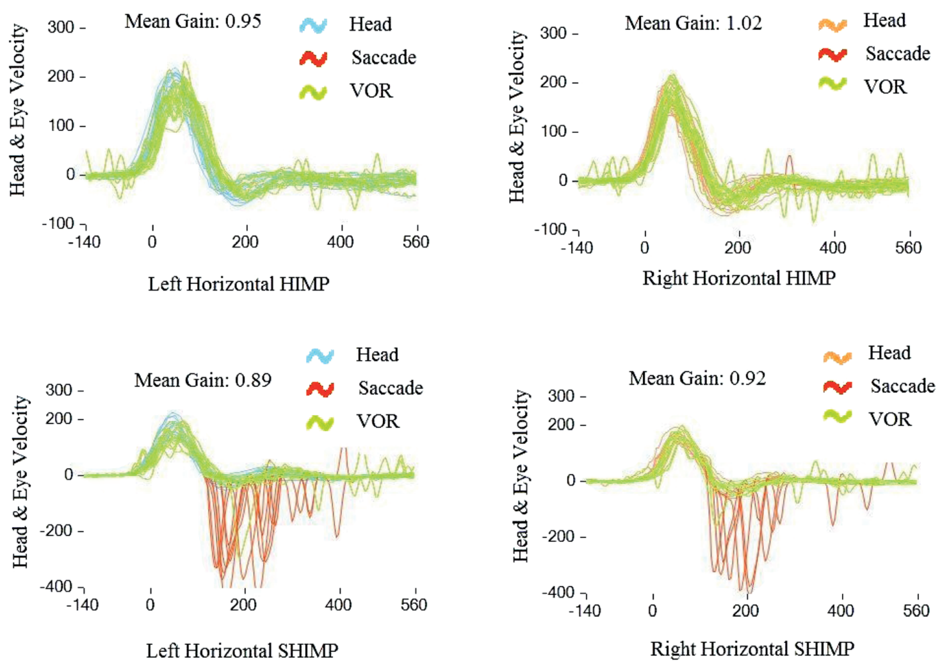

Figure 4. Head and eye velocity tracings of HIMP and SHIMP for a healthy adult's right and left horizontal semicircular canals. During HIMP, the subject maintained gaze on a fixed target ahead and rarely made compensatory saccades or only elicited a few small saccades to correct for head movements. During SHIMP, the target moved with head impulses, and the eyes had to elicit large anti-compensatory saccades back to the target.

for the rightward impulses than the leftward impulses for the horizontal SCCs.[12,15,16,18] This could be due to the VOR goggle system that only measures the right eye.[18] When the head impulse is directed to the right, the right eye makes a larger rotation to fix the visual target ahead instead of when the head impulse is directed to the left, resulting in a higher VOR gain for right-eye movement.[18] Furthermore, the medial rectus muscle has stronger movement than the lateral rectus muscle.[16] Therefore, the VOR gain during head movement is higher for the right than the left side.[16] Another possible cause of higher VOR gain on the right side could be hand dominance. The right-handed tester tends to deliver higher velocities for the right side than the left side.[12,25]

Table 3. Mean ± Standard Deviations (SDs) of Horizontal Semicircular Canals (SCCs) SHIMP Anti-compensatory Saccade Latencies and Amplitude for Both Right and Left Ears in Each Age Group

Age Group	Side	Mean ± SD of Saccade Latencies	Mean ± SD of Saccade Amplitude
20-40	Right	193.20 ± 33.85	−313.85 ± 49.01
	Left	187.25 ± 28.59	−321.55 ± 42.69
40-50	Right	186.11 ± 38.51	−282.22 ±30.96
	Left	187.78 ± 63.25	−295.56 ± 66.40
50-60	Right	185.80 ± 22.29	−341.70 ± 38.40
	Left	196.90 ± 22.96	329.60 ± 41.53
60-70	Right	216.31 ± 36.89	−321.31 ± 63.76
	Left	217.44 ± 44.10	−318.31 ± 63.23
>70	Right	202.60 ± 14.76	−224.60 ± 39.97
	Left	197.00 ± 23.04	−201.60 ± 43.69
Average	Right	197.85 ± 33.97	−308.30 ± 56.69
	Left	197.80 ± 39.68	−308.13 ± 61.21

In this study, there were no significant effects on the testing side for anterior and posterior SCCs. This finding is consistent with a previous study that reported no significant difference in the VOR gain values between the right and left sides for the vertical canals,[16] although a previous study found significantly higher VOR gain values for the right than the right-left anterior canal.[18] The VOR gain values for the vertical canals are more varied than the horizontal canals,[18] resulting in the differences between the VOR gain findings for the vertical canals between studies.

In this study, age did not affect the HIMP VOR gain values and asymmetry ratios among healthy adults for all SCCs, at least up until the 70s. Additionally, we also found that the horizontal SHIMP VOR gain values did not decline with age. This study is consistent with other studies that found that age did not influence the horizontal SCC VOR gain values at least until 70 years old[15,16] or 80s.[18] In our study, the gain for anterior and posterior SCCs did not change with age, consistent with previous studies that found no significant variations with age

Table 4. Mixed Factor ANOVA of Horizontal Semicircular Canals (SCCs) SHIMP Anti-Compensatory Saccade Latency and Amplitude Based on the Side (Right and Left Ear) and Age Groups

Anti-compensatory Saccade	*F*	*df*	*P*
Latency			
Side	0.007	1	.934
Age	2.283	4	.072
Side × Age	0.359	4	.836
Amplitude			
Side	0.246	1	.622
Age	7.347	4	<.001**
Side × Age	0.779	4	.544

**Significant at the level of .05.

until the 80s for the anterior SCCs[16,18] and posterior SCCs.[16] Aging has been reported to degenerate vestibular sensory hair cell receptors and vestibular afferent nerve fibers.[17] When aging affects the VOR function, the cerebellum can repair the VOR function, so the aging effect on the VOR function could be more negligible observed.[18]

There were small but significant gain differences between HIMP and SHIMP for both right and left ears. The HIMP and SHIMP gain differences in this study were around 0.030-0.040, consistent with previous studies that found higher HIMP than the SHMP gain values with differences of 0.050[21] or 0.060.[3] The difference could be ascribed due to the de-saccadic algorithm or VOR gain suppression at around 80-90 ms toward a target during body rotations[3,21,26] or early saccades due to predictable head impulses, or aging effect.[21] In this study, caution was taken to reduce SHIMP head impulses' predictability, as suggested by a prior study.[21,27] While we found no significant changes in VOR gain values with increasing age, we can suggest that the VOR suppression[3,21,26] is the primary mechanism of gain differences between HIMP and SHIMP, as reported previously.

While HIMP did not elicit or exhibit only a few compensatory saccades, all healthy subjects in this study elicited anti-compensatory saccades in SHIMP. The SHIMP anti-compensatory latency did not change with age. However, the anti-compensatory saccade amplitudes for elderly adult subjects aged above 70 were smaller than the younger age groups. A study found that the older adults generated more covert and overt compensatory saccade on HIMP with no significant differences in the saccade latency than the younger adults.[28] This could occur due to the impairment in the saccade-generating mechanism by cerebellar inhibition.[28] As a result, aging could reduce the anti-compensatory saccade amplitude in SHIMP. Further studies that identified the effects of age on both HIMP compensatory saccade and SHIMP anti-compensatory saccade may confirm the findings. On the contrary, the saccade latency was less affected as there could be an adaptation of vestibular loss or that the saccade latency is a mechanism that could be learned by individuals.[28]

This study confirms the previous findings that the HIMP has good test-retest reliability and that the VOR gain values are stable with age. Additionally, we also reported test-retest reliability and reference values for SHIMP measurements in adults. This study found that the SHIMP testing is quick, easy to administer, and could be well-tolerated by all subjects. The findings indicate that both paradigms can be helpful to investigate the diagnosis of abnormal horizontal SCCs. As to the limitation of the study, the SHIMP test-retest reliability was not assessed in patients with vestibular disorders. Further research that uses the test-retest reliability to assess residual vestibular functions in patients with peripheral vestibular losses may increase its utility as a complementary test to HIMP.

CONCLUSION

Both HIMP and SHIMP measurements using vHIT had good test-retest reliability and validity to assess high-frequency VOR. This study shows that the HIMP and SHIMP testing are stable in respect of age. Both HIMP and SHIMP are useful in diagnosing horizontal SCCs function. While anti-compensatory saccade latency did not change with age, there is an age-related change in anti-compensatory saccade amplitude. These reference values allow for the results to be used to diagnose peripheral vestibular disorders of the SCCs function using both HIMP and SHIMP.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Universiti Kebangsaan Malaysia (UKM) University (JEP-2017-569).

Informed Consent: Written informed consent was obtained from all participants who participated in this study.

Peer-review: Externally peer-reviewed.

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