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Differences in Video Head Impulse Test Gains From Right Versus Left or Outward Versus Inward Head Impulses

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Objective: To investigate the effect of the right/left and outward/inward head impulses on video head impulse test (vHIT) gains.

Methods: Video head impulse test gains were calculated by recording the right eye movements with an infrared camera in a cohort of 24 healthy subjects (26-39 years old, 30 ± 9 years old). We compared the vHIT gains in four different situations in which the right and left lateral semicircular canals (LSCC) were stimulated through outward or inward head impulses.

Results: The vHIT gains from stimulating the right LSCC were significantly larger than those stimulating the left LSCC, regardless of whether the head impulse was outward or inward (1.06 ± 0.1 by right outward vs. 0.98 ± 0.08 by left outward, P = 0.003; 1.02 ± 0.1 by right inward vs. 0.92 ± 0.07 by left inward, P < 0.0001). The mean difference in vHIT gain between stimulating the right or left LSCC was 0.09. The gains from outward vHITs were significantly larger than those from the inward tests, regardless of the LSCC side stimulated (1.06 ± 0.1 from right outward vs. 1.02 ± 0.1 from right inward, both stimulating the right LSCC, P = 0.013; 0.98 ± 0.08 from left outward vs. 0.92 ± 0.07 from left inward, both stimulating the left LSCC, P = 0.001). The mean difference in the vHIT gains between the outward and inward tests was 0.05.

Conclusion: The right/left vHIT gain difference (0.09) is higher than the outward/inward vHIT gain difference (0.05). These are independently significant differences when using a vHIT system, which records movements in the right eye. An understanding of these differences may be helpful when interpreting vHIT results.

Key Words: Video head impulse test, gain, diagnostic, vestibular testing.

Level of Evidence: 4

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INTRODUCTION

The head impulse test is a clinical tool used to quantitatively evaluate the function of the vestibulo-ocular reflex (VOR) of the semicircular canals. Although scleral search coil recording has been the gold standard method for these assessments, the video head impulse test (vHIT) has shown comparable utility and is now considered a viable alternative procedure.1,2 The VOR helps the eyes keep track of the target while the head is constantly moving. The vHIT gain is the ratio of the eye movement to the head movement in a specific plane of each semicircular canal. If the gain is not sufficient, a retinal error occurs, and corrective saccades subsequently ensue such that refixation on the target is possible. As the vHIT gain decreases, the frequency and peak amplitudes of the corrective saccades increase.3–5

The main outcome of a vHIT is the gain, although the parameters for the corrective saccades have been suggested to be used for the evaluation of vestibular dysfunction.3,4 vHIT gains can be analyzed quantitatively, and normative vHIT values stratified by subject age have recently been reported.5–8 However, there have also been several reports that vHIT gains can differ not only by the direction of the head impulses used in the test but also by whether these impulses are outward or inward in the lateral semicircular canal (LSCC) plane, with no upward or downward gain differences being observed in the vertical planes.8–10 Because the vHIT is now widely used, it is important to comprehensively understand the extent to which vHIT gains will differ when using right/left and outward/inward impulses in the test.

In our current study, we investigated the impact of right/left as well as outward/inward head impulses on the gains measured in the vHIT. These gains were compared in four different situations, that is, where the right and left LSCCs were stimulated by outward or inward head impulses. We also reviewed the current literature on this subject and discuss possible mechanisms to explain our present findings.

MATERIALS AND METHODS

Subjects

This study recruited 24 normal subjects (13 females and 11 males, aged 31 ± 4 years) with no history of vestibular or neurologic impairment, posture or gait abnormalities, or hearing

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problems. All subjects displayed normal hearing as confirmed by air-conduction pure tone audiometry and provided written informed consent to participate after the study purpose and procedures were fully explained. This study protocol was approved by our institutional review board.

Video Head Impulse Test and Head Impulses in Four Different Situations

The function of the lateral semicircular canal was assessed in the study subjects using an ICS Impulse 3-D vHIT system (GN Otometrics, Taastrup, Denmark). This device comprises a lightweight pair of goggles integrated with a video-oculography camera, a mirror to reflect the image of the patient’s right eye into the camera, and an inertial system to measure head movements. During the test, subjects were seated wearing goggles with their head and body facing a target light-emitting diode (LED) positioned on a wall at a distance of 1 m. The operator stood and held the subject’s head from behind and instructed the subject to continually look at a dot located on the wall.

For outward head impulses, the subject’s head facing the LED was moved laterally with a small amplitude (5°–15°) and a mean high peak velocity (227 ± 16/second to stimulate the right LSCC; 228 ± 14/second to stimulate the left LSCC), resulting in the subject facing to the right or left (Fig. 1A). Each subject was subjected to a minimum of 10 head impulses in the horizontal plane to each side (left or right), with unpredictable timing and direction. For inward head impulses, the subject’s head, which was facing toward the left and right sides with the eyes staring at the LED in front, was moved centrally with a small amplitude and a mean high peak velocity (233 ± 14/second to stimulate the right LSCC; 245 ± 15/second to stimulate the left LSCC), resulting in the subject facing forward (Fig. 1B). A single examiner who had performed thousands of these tests over more than 4 years performed these vHIT procedures.

The evaluated parameter was a vHIT gain. The software provided by the manufacturer automatically calculated these gains, defined by the ratio of the area under the curve, the term used by the manufacturer to quantify the area under the trajectory, for the eye movements divided by that for the head movements. The trajectory is in terms of velocity; this area represents the distance traveled by the eye and by the head.

Statistical Analysis

Statistical comparisons of vHIT gains obtained in the different situations were made using the Wilcoxon signed rank test. SPSS version 21.0 (IBM Corp., Armonk, NY) was used for all statistical analyzes. *P* values of < 0.05 were considered statistically significant. The results are reported as a mean ± SD.

RESULTS

Differences in Video Head Impulse Test Gains When Stimulating the Right Versus Left LSCC

The vHIT gains from stimulating the right LSCC were significantly larger than those obtained from stimulating the left LSCC (1.06 ± 0.1 by right outward vs. 0.98 ± 0.08 by left outward, *P* = 0.003; 1.02 ± 0.1 by right inward vs. 0.92 ± 0.07 by left inward, *P* < 0.0001) (Fig. 2). In the outward vHIT, 19 (79%) subjects showed a higher gain when stimulating the right LSCC compared with the left LSCC, whereas two cases (8%) showed the
same vHIT gains under both impulse conditions. In the inward vHITs, 22 (92%) subjects showed a higher gain from a right LSCC stimulation.

The interaural (right vs. left) vHIT gain differences stimulating the right and left LSCCs in outward vHIT were 0.08 ± 0.08. And the interaural vHIT gain differences in inward vHIT were 0.1 ± 0.09. These interaural (right vs. left) vHIT gain differences were similar regardless of the direction (inward or outward) of the head impulses. Overall, the vHIT gain stimulating the right LSCC was higher than that stimulating the left LSCC by 0.09.

The gain asymmetry values were 3.9% ± 4.1% for outward vHIT and 5.1% ± 4.6% for inward vHIT, which were not significantly different from each other. Overall, the mean gain asymmetry value was 4.5%, regardless of the direction (inward or outward) of the head impulses.

**DISCUSSION**

It has been reported that the vHIT gains for the rightward impulses are higher than those for the leftward impulses when recording right eye movements. A prior study using a scleral search coil system reported that the gains for the adducting eye exceeded those of the abducting eye as the head acceleration increased, and that the gain asymmetry could reach 15.3% at a high head impulse acceleration (6000°/s²). The authors of that study recommended binocular recording for accurate measurements of the VOR at high accelerations to avoid this right/left VOR gain difference because VOR gains were symmetrical in both directions when the abducting eye was analyzed in this way. Later studies using a vHIT system with eye movement recording in only one eye (right side) also reported similar findings but with smaller differences that those using the scleral search coil. The right/left vHIT gain asymmetry has been previously recorded to range from 2.2% to 10.4%, with vHIT gain differences of 0.02 to 0.07, which are comparable to our current results (gain asymmetry of 4.5% and right/left vHIT gain difference of 0.09). It has also been reported that the VOR gains from a rightward head
rotation were significantly greater than those from a leftward head rotation, regardless of the target distances and peak head velocities, and this directional difference (upward/downward) was not observed in the anterior and posterior canal planes. Thus, it is advisable to better understand this right/left gain difference when interpreting the results in the LSCC plane using a vHIT system and recording the movements in only one eye. This right/left gain difference might be caused by a synaptic delay and by different firing characteristics of the additional abducens internuclear neurons in the VOR pathway from the stimulated horizontal semicircular canal to the medial rectus muscles of the ipsilateral adducting eye (Fig. 3). Another possible mechanism underlying the right/left vHIT gain difference is the medial rectus muscles, which have a greater maximum active force than the lateral rectus muscles by about 26% (Fig. 3).

The effect of outward and inward head impulses on the vHIT gains was investigated in two different vHIT systems in a previous study, which reported that the vHIT gain for outward impulses was significantly larger than that for inward impulses, regardless of the device used. The outward and inward vHIT gain differences reported thus far in the literature have ranged from 0.05 to 0.09, which is consistent with the higher outward vHIT gain difference of 0.05 in our present study. Notably, however, based on our current findings, this higher outward impulse gain difference would be markedly increased to 0.14 when combined with the right/left difference of 0.09, for example, outward vHIT gains (1.06 ± 0.1) stimulating the right LSCC versus inward vHIT gains (0.92 ± 0.07) stimulating the left LSCC. Therefore, we would advise to not alter the stimulation method (outward or inward) when conducting these vHIT assessments.

One possible mechanism for the outward and inward vHIT gain difference might be closely related to the end eye position, which is the neutral position for the inward head impulse and the lateral gaze position for the outward head impulse (Fig. 1). Unlike the neutral eye position, the lateral gaze position requires a position signal that can hold the eye in the lateral gaze position and overcome the elastic restoring force arising from the stretching of the antagonist extraocular muscle with which it is paired (Fig. 3). Experimental evidence has shown that the oculomotor neurons receive a signal that includes both the desired eye velocity signal, which is sent by a direct VOR pathway from the LSCC along to the abducens and oculomotor nuclei, and the instantaneous eye position signal, which is sent by the brainstem neural integrator that mathematically time-integrates the velocity signal to yield a position signal. For horizontal eye movements, the integrating neurons lie in the nucleus prepositus hypoglossi region of the pons. Thus, inward head impulses ending with the neutral eye position do not need a position signal; however, the outward head impulses produce a velocity signal with a position signal, which might produce a higher vHIT gain (Fig. 1). Alternatively, the stretching of the muscle may be mediated by the neural pathways connecting the cervical afferents to the secondary vestibular neurons, which project directly to the extraocular muscle motoneurons. The cervico-ocular reflex (COR) is a reflexive eye response elicited by rotation of the neck. The proprioception of muscles and the facet joints of the cervical spine could supplement this reflex in normal subjects. A third possible mechanism is that inward impulses are more predictable than outward impulses, which can lead to less contraction of cervical muscles and a decreased alertness that could contribute to a lower gain of the VOR.

The clinical implications of our findings warrant discussion. When using a vHIT system that records the movement in one eye, an otologist should be aware that the vHIT gain differs by side, which is highly relevant given that a vHIT gain of less than 0.8 is commonly considered pathologic regardless of the side. Based on our present findings (vHIT gains from right outward head impulses = 1.06 ± 0.1; vHIT gains from left outward head impulses = 0.98 ± 0.08), 95% of observations are likely to fall within 2 standard deviations of the mean. There is a 97.5% probability that the vHIT gain will be ≥ 0.86 and ≥ 0.82 for the right and left LSCCs, for which the right/left difference of the lower limits is 0.04. If the vHIT gain of a dizzy patient is 0.83 on both sides, it may be regarded as considerably decreased in the right LSCC compared to the left LSCC, and additional consideration of the presence of pathologic corrective saccades when stimulating the right LSCC might be helpful in interpreting the results.

Because the possible mechanisms underlying right/left vHIT gain differences are related to the central VOR pathways and/or extraocular muscles, which might not be influenced by the peripheral vestibular disorders (Fig. 3), we postulate that they would be still be present in patients with these conditions. However, the outward and inward vHIT gain difference mechanisms might still be influenced by a peripheral vestibular disorder (Fig. 1). In the acute period after loss of unilateral labyrinthine function, the neural integrator becomes dysfunctional or leaky, possibly resulting in a decreased vHIT gain for outward head impulses, with less difference between the outward and inward vHIT gains. By contrast, COR might supplement VOR in patients with vestibular disorders and with a persistent outward and inward vHIT gain difference. Further studies in patients with vestibular disorders to investigate this difference of vHIT gains following outward and inward head impulses would be of interest.

Although active and passive head rotations did not result in significant differences in VOR gains in normal subjects in a previous report, the same study did show that active head impulses yield a higher VOR gain than passive head impulses, with an early onset of compensatory preprogrammed eye movement in patients with vestibular dysfunction. Thus, the outward impulses that the subject cannot predict the direction of the head impulses is advantageous to detect the vestibular dysfunction, although outward head impulses might cause neck pain, especially in patients with arthritis or neck trauma.

CONCLUSION

The right/left vHIT gain difference (0.09) is higher than the outward/inward vHIT gain difference (0.05).
These are independently significant differences when using a vHIT system that records movements in the right eye. Thus, we would advise not altering the stimulation method (outward or inward) when conducting these vHIT assessments. An understanding of these differences may be helpful when interpreting vHIT results.

BIBLIOGRAPHY


