Specificity of the Video Head Impulse Test System

Andrew DeLong

Vanderbilt University

Committee: Devin McCaslin, Ph.D. (Director)
Gary Jacobson, Ph.D.
Jill Gruenwald, Au.D.

Abstract

The vestibulo-ocular reflex (VOR) is responsible for maintaining clear vision on a target in the presence of head motion. A functional VOR driven by a healthy peripheral and central allows for three assumptions: eye velocity and head velocity are equal; eye rotation and head rotation occur in equal and opposite axes; and movements of the head and eye are synchronous. Caloric irrigations have served as the gold standard for assessing lateral semicircular canal function, and until recently video technology inadequately captured eye movement. With the advent of lighter, better-fitting goggles and improved video resolution, the video head impulse test (vHIT) is capable of recording saccades during and following high velocity, low amplitude head thrusts. The purpose of this project was to determine specificity of the EyeSeeCam video head impulse system on young normal participants. Normal vestibular function was confirmed with caloric irrigations, and asymmetry across all subjects was found to be 4%, suggesting sufficient specificity for clinical use pending sensitivity data in a clinical population.

Introduction

The vestibulo-ocular reflex (VOR) is responsible for maintaining clear vision on a target in the presence of head motion. This reflex drives compensatory eye movements opposite the direction of high frequency head movements to keep visual targets on the fovea of the retina. This reflex is triggered and maintained primarily by the ten organs of the inner ears of balance: six semicircular canals (SCCs, three on each side) and four otolith organs (the left and right saccule and utricle). The SCCs encode neural firings that represent angular head acceleration, and the otolith organs encode for linear acceleration.

Together, these organs along with visual and proprioceptive sensory systems allow us to orient ourselves in space relative to the environment (Barin & Durrant, 2000). Insult to any of these organs is likely to result in imbalance, dizziness, or other vertiginous symptoms. A complete audiovestibular test battery can assess the integrity of the peripheral organs; central vestibular system comprised of portions of the cerebellum, reticular formation, thalamus, and cerebral cortex; and neural connections between the two. A functional VOR driven by healthy peripheral organs and central vestibular system allows for three assumptions: eye velocity and head velocity are equal; eye rotation and head rotation occur in equal and opposite axes; and that the movements of the head and eye are synchronous (Aw et al., 1996). Impaired SCC function will result in low VOR gain when moving the head toward and in the plane of the lesioned organ, resulting in an eye velocity-head velocity ratio of less than one. Inadequate VOR gain means the eye is not driven 180 degrees out of phase with the head. In order to maintain clear vision on the fovea of the retina, a compensatory saccade is generated to return the eye's gaze to the intended target. Such saccades are useful in the secondary assessment of peripheral vestibular system impairment.

First introduced in 1988, Halmagyi and Curthoys found that impulses of the head toward a completely damaged peripheral organ yielded a correcting saccadic eye movement. Since its initial use as an assessment of vestibular function in comatose or unresponsive patients (McCaslin, Dundas, & Jacobson, 2008), the head-impulse test (HIT), also referred to as the head thrust test or Halmagyi head thrust, is most often used as a bedside screening by audiologists, general practitioners, physical therapists, and neurotologists. Head impulses assess the integrity of the vestibular system by way of the oculocephalic, or doll's eye, reflex, and most often to assess the lateral semicircular canal ipsilateral to the direction of the thrust. If a lateral SCC is lesioned, the patient may demonstrate a catch-up ("overt") saccade to reacquire a stationary target when the head is thrust toward that affected ear (McCaslin et al., 2008). Research has shown that although saccades seen post-impulse are detectable to the trained clinician, saccades occurring during the head thrust are virtually impossible to detect with the naked eye (Weber, Aw, Todd, McGarvie, Curthoys, & Halmagyi, 2008; Black, Halmagyi, Thurtell, Todd, & Curthoys, 2005). These "covert" saccades, like the overt saccades, suggest a unilateral impairment of the horizontal semicircular canal. However, unlike the overt saccades, the covert saccades occur during instead of following the head movement. Thus, at the end of the head movement there may be little, if any, residual distance to close between the eye and the target.

The HIT may be conducted as one of three iterations: as a bedside screening test using the naked eye, as a computerized test using a scleral search coil, and using video recording technology. The bedside screening is conducted using a passive (examiner moves patient's head), rapid head turn in the plane of the lateral SCC, which requires a 30 degree forward tilt for a sitting patient (McCaslin et al., 2008; Schubert, Tusa, Grine, & Herdman, 2004). The patient is instructed to maintain gaze on a target roughly one meter at 0° azimuth and by applying a high velocity (50-250 °/s), high acceleration (2000-4000°/s^2), low amplitude (5-20°) (Aw, Todd, & Halmagyi, 2010; MacDougall, Weber, McGarvie, Halmagyi, & Curthoys, 2009; Schubert et al., 2004; Walker & Zee, 2000) head impulse to the patient's head , a clinician observes the patient's eyes for the presence of the overt saccade at the end of the head thrust as the patient attempts to maintain gaze on the target. Normal results will reveal a nearly 180 degree out-of-phase movement of the eyes relative to the head,that is indicative of an intact VOR in the plane of the lateral SCCs. Minimal experiential training is required for clinicians to produce reliable, repeatable head thrusts. Sensitivity and specificity estimates for the bedside HIT test in cases of incomplete vestibular hypofunction have ranged from 46% and 94% (McCaslin et al., 2008), to 58% and approximately 71% (Schubert et al., 2004), to 34% and 100%, respectively (Beynon, Jani, & Baguley, 1998). The simplicity of the preparation and brevity of the test are merits that have made this appealing to physician and non-physician practitioners. However, without sensitive and objective recording techniques that are capable of detecting the presence of covert saccades this test is limited to a gross screening tool that might help to predict the results of caloric testing.

Scleral search coil HIT testing requires cumbersome equipment, additional space, and additional equipment that make the technique impractical. A topical anesthetic is administered to the patient's cornea and a hard contact lens containing a coil of wire around the perimeter is placed over the cornea. The patient is then placed in a magnetic field generated by a frame surrounding the patient's head or body, and any subsequent movements of the lens-laden eye may be monitored detected and traced in a three-dimensional field. A bite bar or dental tray is also used to trace head velocities to allow for comparison between eye and head movements (MacDougall et al., 2009; Schmid-Priscoveanu, Bohmer, Obzina, & Straumann, 2000). Passive head movements are applied to the head as in bedside testing, and results are measured by voltage differences induced in the magnetic field. This technique was the first used to detect the presence of covert saccades. The technique offered a precise measure of eye position relative to head movement. However, the patient discomfort, need for additional equipment, preparation and testing time has made this recording technique useful only for research studies.

The video HIT (vHIT) is the most recently developed HIT recording technique. Testing procedures require the same low amplitude, high velocity head impulse, but only require patient to wear a pair of goggles. Similar to goggles used for videonystagmography, cameras are affixed to lightweight frames. The cameras track pupil movement compared to head movement monitored by gyroscopes also affixed to the frames. The goggles are lightweight and able to be tightened to the patient's head, minimizing inertial slips when the head is thrust in any direction. The lightweight goggles afford video HIT testing a level of ease not found in other methods. The vHIT is capable of recording overt and covert saccades, and accurate recordable tracings allow clinicians and colleagues to further review results long after the patient has left the clinic.

Currently, the gold standard for assessing lateral semicircular canal function is the bithermal caloric irrigation as it permits the left and right lateral SCCs to be assessed independently (Perez & Rama-Lopez, 2003). The vestibular system optimally encodes for head rotations of roughly 0.1 to 3 Hz (Barin, 2008), but caloric irrigation evokes a response similar to that of a 0.003 Hz rotation of the head (Perez & Rama-Lopez, 2003; Barin, 2008). The head impulse test measures the response of the VOR to a high frequency stimulus. While the comparison between head impulse test and caloric test results is simple as it measures similar parameters from the same end organs, the frequency responses of either test may be influenced by the velocity storage or a number of examiner effects (Barin & Durrant, 2000; Barin, 2008). If the caloric test and HIT produce different test results there may be produced clinically useful diagnostic patterns.

Previous investigators have attempted to measure the sensitivity and specificity of the bedside HIT. The results of these investigations have shown that the bedside HIT is sensitive only to vestibular system impairments that produce large bithermal caloric test asymmetries (Beynon et al., 1998; Perez & Rama-Lopez, 2003; Schubert et al., 2004).

Few assessments of test performance have been reported for the vHIT to date. These investigations have been conducted on patients with large or complete unilateral impairments caused by unilateral nerve section, and canal occlusion (as cited in McCaslin et al, 2008). Early data on sensitivity and specificity of vHIT test measures suggest 100% sensitivity for these select groups of patients. One study showed that when compared to scleral search coil methods, the vHIT goggles yielded “virtually identical results” (Weber, MacDougall, Halmagyi, & Curthoys, 2009), and MacDougall et al. (2009) also obtained comparable performance when comparing video and search coil recording techniques. These results are encouraging, but they do not necessarily reflect results expected from the general clinical population with partial unilateral vestibular deficits. The purpose of this study is to determine whether the video head impulse test has sufficient specificity to justify use in a typical clinical battery when taken with results from an impaired population.

Methods

Subjects

Seventeen young healthy participants (4 male, 13 female) were enrolled in the study. These individuals ranged in age from 22 to 29 years (mean: 24.79) and reported no history of hearing or vestibular impairment. All participants provided written consent to the study protocol, which was approved by the Vanderbilt Institutional Review Board.

Video Head Impulse Test

Patients were seated facing a wall at a distance of 5 ft (1.54 m). A 1" by 1" (2.54 cm x 2.54 cm) sticker was placed on the wall approximately 4 ft (1.21 m) above floor level served as the visual target. The EyeSeeCam VOG (Munich) goggles were fit snuggly to the patient's head and the video camera adjusted to record left eye movement. Special care was taken to ensure the pupil was centered in the software video display with the curvature of the eye correctly traced. The goggle camera sampled at a rate of 150 Hz.

The EyeSeeCam calibration projects a grid of fixation dots from a projector on the nasal bridge of the goggles. To calibrate, room lights were turned out and participants were instructed to keep their heads still and to fixate on each dot as indicated by the examiner. The indicated target dot changed approximately every second, and each possible path between adjacent, highlighted fixation points was traced at least one time.

During testing, the examiner stood behind the seated participant, and with gloved hands grasped the participant's jawline and guided the head through at least 10 rapid, 5-20° thrusts to each side. Each thrust achieved a velocity of at least 100°/sec, and following each thrust, the head was maintained in the final position rather than returning to the initial position; this technique attempts to limit the masking of overt saccades in the video tracings. Head thrust direction and timing were varied to discourage anticipation. The participants were told to keep their jaw closed and maintain their gaze on the target sticker throughout testing. This protocol was completed at least two times for reliability.

The parameters of the test that will be assessed are the gain of the VOR at 40, 60, and 80 milliseconds post head thrust, gain asymmetry between leftward and rightward thrusts, and differences in eye and head peak amplitudes and latencies as measured in degrees/second and milliseconds, respectively. The peak amplitudes and latencies were determined by visually scanning the tracings for the average peak.

Monothermal Caloric Irrigations

For caloric testing, participants were reclined to 30 degrees above the supine position, placing the lateral SCCs approximately in the vertical plane. Each participant wore videonystagmography (VNG) goggles to record eye movement during caloric stimulation. Warm water (250 mL at 44 degrees Celsius) was irrigated into the external auditory canal over a 20 second interval per ear. Eye movements were recorded for approximately two minutes during and following the irrigations. Using video from the VNG goggles, the slow phase velocity (SPV) of the eyes was measured to assess symmetry. The presence of a unilateral weakness was calculated using the following equation:

$$\frac{|(\text{Left Warm SPV} - \text{Right Warm SPV})|}{\text{Total SPV}} \times 100$$

(Equation 1)

A unilateral weakness based on monothermal irrigations is determined to be present when the responses between the two ears are asymmetrical by 23% or greater (Barber et al., 1971). Results of caloric testing are expressed in degrees/second and percent unilateral weakness, if applicable.

Statistical Methods

One-way analyses of variance (ANOVA) were done to analyze differences in gain by direction, and eye and head peak amplitudes and peak latencies. Eye peak latency and head peak latency was compared across direction using Student's T test. Results are expressed as mean and standard deviation.

Results

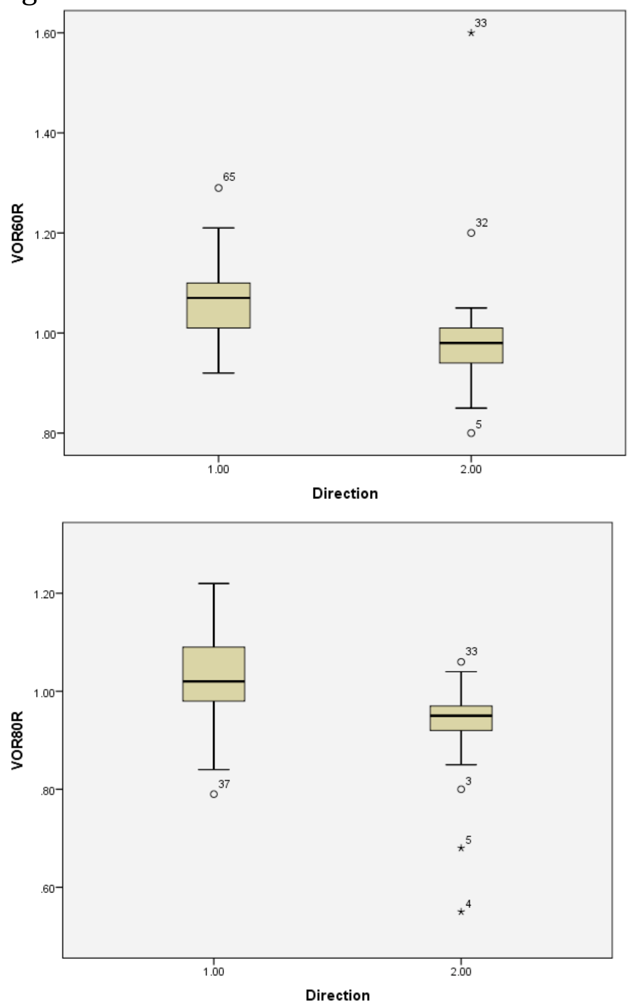
Normal function of the lateral semicircular canal and superior portion of the vestibular nerve was confirmed in each participant with caloric irrigation. Using the vHIT system and protocol, the mean interaural asymmetry across all participants was 4% (S.D. = 0.005). Table 1 shows mean and standard deviation of VOR gain across all subjects at 40, 60, and 80 milliseconds to the left and right, as well as the average standard deviation in the gain values. There was no significant difference between leftward and rightward head impulses when comparing gain values at 40 milliseconds. A significant difference was seen ($p < 0.01$) in gain values between leftward and rightward thrusts at 60 and 80 milliseconds (see figure 1), and no significant difference was seen in standard deviation values at any time interval.

Table 1. VOR Gain

	Direction	Mean	S.D.	p
VOR40	L	1.09	0.14	0.464
	R	1.07	0.10	
VOR60	L	1.07	0.08	0.006*
	R	0.99	0.13	
VOR80	L	1.03	0.10	0.000*
	R	0.93	0.10	
VOR40SD	L	0.0997		0.533
	R	0.0909		
VOR60SD	L	0.1209		0.030
	R	0.0885		
VOR80SD	L	0.0973		0.063
	R	0.0715		

Caption: * indicates statistical significance

Figure 1. VOR Gain at 60 and 80 ms



Caption: 1 = leftward; 2 = rightward.

No significant difference was seen in the peak amplitude or peak latency of either the eyes or the head when comparing leftward thrusts to rightward thrusts (Table 2). Significant differences were seen when comparing eye and head peak amplitudes (p = 0.024) and latencies (p = 0.000), controlling for side. That is, eye peak amplitude values were significantly different from head peak amplitude values in the same direction for both left and right thrusts; statistical differences were also seen in peak latency values.

Table 2. Eye and Head Peak Amplitudes, Latencies

	Direction	Mean (ms)	S.D.	p

Eye Peak Amp.	L	210.17	27.57	0.376
	R	204.09	27.80	
Eye Peak Lat.	L	68.48	15.58	0.089
	R	61.42	17.58	
Head Peak Amp.	L	197.45	23.86	0.169
	R	205.34	22.20	
Head Peak Lat.	L	70.54	10.48	0.546
	R	72.21		

Discussion

The purpose of this study was to determine if the video head impulse test has sufficient specificity for use in a clinical protocol; that is, is the vHIT is capable of finding that patients with normal vestibular function, as measured by caloric irrigations, are indeed normal. All participants were determined to be normal using monothermal warm caloric irrigations. The interaural asymmetry as determined by the vHIT was 4% on average for all participants, which is well within the bounds of normal function (22% interaural difference using caloric irrigation).

It is noteworthy that a significant amount of training and practice is required for the vHIT examiner. Adequate training and practice on colleagues is recommended for accuracy, consistency, and comfort with applying the thrusts to a patient. The technique used for this study also put particular emphasis on applying the head thrusts without rebounding the head, so as not to lessen the distance between the eye and target should a recovery saccade be necessary.

A significant difference was seen between leftward and rightward thrusts at 60 and 80 milliseconds; specifically, VOR gain for leftward thrusts was greater than gain for rightward thrusts. It is likely that this is a byproduct of differences in technique between thrusts in each direction. It appeared in reviewing the tracings that more force was applied to the head for leftward thrusts than rightward, which may be a consequence of examiner handedness preferences. However, the similarity in standard deviation values at each time interval suggests consistency in the technique. While the thrusts ultimately yielded normal values, it may be valuable to assess each clinical examiner and develop clinician-by-clinician normative data. This would appear to be useful for developing broader clinical norms.

Significant differences were also seen between eye peak amplitude and head peak amplitude values in each direction; when the head was thrust to the left, deviation of the eye was greater than that of the head, consistent with the observed gain values >1.00. Thrusts to the right elicited gain values <1.00, indicating that the head deviated further than the eyes. While this achieved statistical significance ($p = 0.000$, $r = 0.681$), the gain did not fall to 0.68, which is the suggested cutoff indicative of a VOR deficit (MacDougall et al., 2009; Weber et al., 2009). Eye and head peak latencies also differed in both directions. More specifically, the peak of eye movement occurred prior to the peak of head movement. It would seem that such results would be impossible without participant anticipation, but head impulses were delivered in a random direction at random time intervals in an attempt to prevent such anticipation. Such an explanation would have required that the participant anticipate the amplitude and acceleration of the thrust immediately before it was applied.

A more likely explanation is that some degree of slippage between the goggles and the head still exists, as was indicated with earlier generations of larger VNG goggles. Empirically, examiner hand placement during the thrust, hairstyle, and fit of the elastic strap all affected slippage: hand placement on the elastic headband may introduce slippage on the goggles; longer, smooth hair served as an added barrier between the elastic strap and the scalp; and the goggles must be fit snuggly to each participant. Preliminary data from our other patients in our lab shows that slippage may be present in other tracings (McCaslin, D.L., personal communication). Weber et al. (2009) demonstrated no significant slippage in their experiment by comparing head motion measured by a dental impression-mounted search coil and the inertial measurement unit (IMU) contained in the goggles. Without this technique available, it cannot be determined whether or not slippage affected the trials, but serves as a likely explanation.

Conclusions and Future Direction

The video head impulse test is sufficiently specific for use in a clinical protocol, agreeing with previous research using various vHIT systems (MacDougall et al., 2009; Perez & Rama-Lopez, 2005; Weber et al., 2009). However, seen within this set of young normal participants were differences in VOR gain between leftward and rightward thrusts at 60 and 80 milliseconds. This, taken with differences in eye and head peak latencies and amplitudes, may be resultant of examiner technique and goggle slippage. Prior to clinical use, clinicians should receive ample training and practice time to apply appropriate and consistent thrusts. It may behoove clinical directors to oversee practice of the technique and analyze normative data per clinician; significant variability may result simply from individual technique.

Researchers should continue to establish normative data for vHIT sensitivity until the widespread availability allows clinics to establish site-by-site norms. The inertial measurement capabilities of the goggles and small relative size allow for the assessment of the posterior and anterior semicircular canals without the discomfort of caloric irrigation and unique head angle. With some level of software development, goggles currently used for video head impulse testing may soon prove to be useful for an entire videonystagmography test battery. In its current state, the goggles have shown to be useful in screening patients who are suspected to be normal prior to caloric irrigation.

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