COLLECTING NORMATIVE DATA FOR VIDEO HEAD IMPULSE TESTING, HORIZONTAL AND VERTICAL MEASURES

by

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ABSTRACT

A new test of vestibular function, video head impulse testing (vHIT), evaluates function of the anterior and posterior vertical semicircular canals as well as the horizontal canals. Our goal was to collect normative data for vHIT in both horizontal and vertical planes. Horizontal data was compared to bithermal calorics. Data was collected from 19 participants with normal auditory function and no complaints regarding dizziness or balance. All occulomotor results were normal. Bithermal water caloric irrigations revealed an average unilateral weakness and directional preponderance of < 10%. For vHIT, average velocity gains (comparison of head velocity to compensatory eye velocity) were calculated for right lateral and left lateral maneuvers using instantaneous velocity measurements at 40, 60, and 80 ms and using the velocity regression measurement from 1-100 ms. Average instantaneous velocity gain at 60 ms was 1.175 for right lateral and 1.159 for left lateral. Average velocity regression gain (1-100 ms) was 1.147 for right lateral and 1.172 for left lateral, with an average gain asymmetry of 2.6%. The RALP average velocity gain, based on the velocity regression measurement from 1-100 ms, was 1.514 for right anterior and 1.665 for left posterior, with an average gain asymmetry of 7.26%. The LARP average velocity gain, based on the velocity regression measurement from 1-100 ms, was 0.923 for left anterior and 0.876 for right posterior, with an average gain asymmetry of 7.11%. Unlike with laterals, consistent vertical responses were more difficult to obtain. Contributing factors are camera slippage, inexperience, technique, and the constrained eye movement in the vertical plane.

INTRODUCTION

We have two types of sensory structures that provide us with information in regards to balance. Angular head and body acceleration (e.g., spinning or tumbling) are sensed by three peripheral receptors collectively known as semicircular canals (Horizontal, Anterior Vertical, and Posterior Vertical canals). These receptors are encased in the right and left temporal bones of our skull and are oriented 90˚ to each other, thus allowing encoding of motion in three dimensional space. Linear acceleration and our relationship to gravity are sensed by two peripheral receptors collectively known as otolithic membranes (the utricle and saccule) also encased in the temporal bones. All of these structures are part of the inner ear (three semicircular canals and two otolithic membranes housed in each inner ear). Damage to the semicircular canals often results in balance issues, specifically a feeling of dizziness and vertigo, whereas damage to otolithic membranes results in a sensation of floating, moving up and down, or moving side to side.

Robert Bárány (1907) first demonstrated that warm and cool water irrigation of the external auditory canals activated the horizontal semicircular canals (Barin, 2016). Irrigation resulted in the activation of the vestibulo-ocular reflex (VOR), a compensatory eye movement elicited by head movement, wherein the eyes move in an equal and opposite way in reference to head movement in order to keep an object in focus on the fovea of the eye. In the 1960's this reflex was measured by surface electrodes placed at the outer canthi of each eye. The eye is a dipole with a greater positive charge anteriorly and a greater negative charge posteriorly, generated by cell metabolism in the retina.

When the eyes move, the charge varies between the electrodes, allowing recording of the VOR. This test is known as Electronystagmography (Barin, 2016). More recently, in the 1990's, the introduction of infrared cameras inset into goggles worn by the patient allowed an accurate measure of the VOR without using electrodes. This test is known as Videonystagmography (VNG). ENG/VNG has long been the accepted gold standard measure for the identification of vestibular system impairment, specifically by using caloric irrigation to evaluate horizontal semicircular canal function (McCaslin & Jacobson, 2009). VNG involves evaluation of vestibular function in a variety of ways. The test battery includes oculomotor testing, position and positional testing, and caloric irrigation (a test of the aforementioned vestibulo-ocular reflex). The test typically takes approximately 1 hour and involves irrigation of the ear canals with warm and cool water or air in order to stimulate the horizontal semicircular canals. Because of structural limitations (location and orientation of the semicircular canals in the skull), VNG irrigation can only reliably be used to evaluate horizontal canal function and cannot evaluate anterior and posterior vertical canal integrity. The process of irrigation can be uncomfortable for the subject, as the process involves bathing the ear canals with warm and cool water to elicit a response from the horizontal semicircular canal on the side being irrigated, which results in a feeling of dizziness and possibly nausea. Heated or cooled air can also be used to elicit the VOR. While irrigation with air is more comfortable than using water, the feeling of dizziness and nausea remains.

Recently (2009), the Video Head Impulse Test (vHIT) was introduced as a new test of vestibular function that is quick, portable, and causes little patient discomfort (Curthoys et al., 2016). vHIT allows us to clinically evaluate horizontal AND vertical (anterior and posterior) semicircular canal function in approximately 10-15 minutes without the need for irrigation and the resulting vertigo, dizziness, and nausea (MacDougall, McGarvie, Halmagyi, Curthoys, & Weber, 2013). Additionally, stimulation of the vestibular system by rapid, very short distance head accelerations with the vHIT is a more natural way of activating the semicircular canals. Due to the recent development of the vHIT, there is not a lot of normative data published for the horizontal semicircular canals and even less so for the vertical semicircular canals.

Several investigators have published normative data for vHIT (McGarvie, MacDougall, Halmagyi, Burgess, Weber, & Curthoys, 2015; McCaslin, Jacobson, Bennett, Gruenwald & Green, 2014; Matino-Soler, Esteller-More, Martin-Sanchez, Martinez-Sanchez & Perez-Fernandez, 2014; Murnane, Mabrey, Pearson, Byrd and Akin, 2014; McGarvie, MacDougall, Halmagyi, Burgess, Weber, & Curthoys, 2015). In 2014, McCaslin et al. conducted a research study to calculate the sensitivity and specificity of the vHIT compared to caloric irrigation for detecting horizontal semicircular canal impairment. However, they did not evaluate vertical canal function. Their results showed that for vHIT to reveal a significant asymmetry or gain reduction there had to be approximately a 40% unilateral weakness in caloric testing. Conversely, a 25% unilateral weakness by caloric testing is considered to be borderline abnormal. Their results revealed that vHIT may not be as sensitive to horizontal canal impairment as VNG. However, vHIT is in the early stages of clinical development and as evaluative techniques improve, sensitivity and specificity of the test may also improve. In spite of possible sensitivity limitations, using vHIT to assess subjects who complain of dizziness may be advantageous due to 1) the speed of the test, 2) the natural activation of the SCCs, (we eliminate irrigation of the ear canals and inducing dizziness and nausea), 3) portability of the system and 4) it is the only vestibular test to allow analysis of vertical semicircular canal function.

The vHIT system includes a laptop and an infrared camera attached to a pair of goggles. The camera tracks pupil movement during rapid, high velocity, short distance head movements to evaluate the VOR. For an individual with a normal functioning VOR, we expect to see equal and opposite compensatory eye movements in response to head movements. We also expect corrective saccadic movements to be absent for normal functioning adults. There are two types of saccades: overt and covert saccades. Overt saccades are correctional eye movements that occur at or after the termination of the head impulse. When the compensatory eye

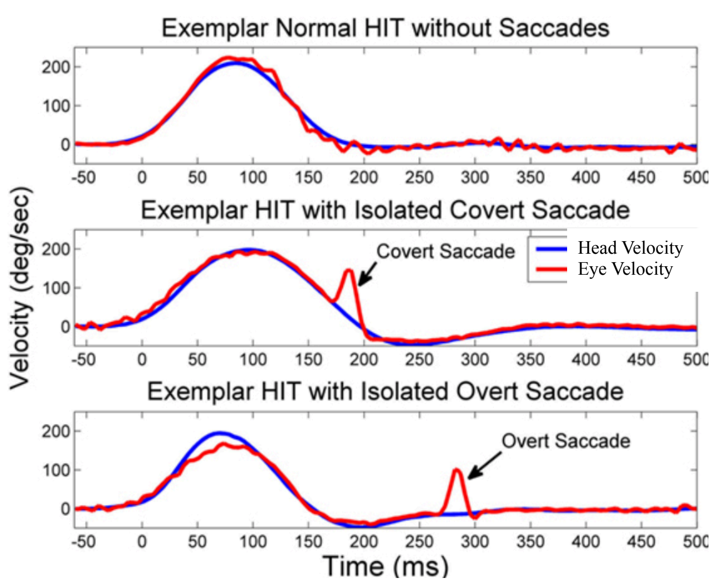

Figure 1. *Covert vs. overt saccades. Covert saccades occur during the head impulse, while overt saccades occur at or after the termination of the head impulse. In this example, the head impulse ends at approximately 200 ms.*

movement is insufficient, the visual system initiates an overt saccade to bring the eye back to the visual target (McCaslin et al., 2014). Covert saccades are correctional eye movements that occur during the head movement. McCaslin et al. (2014) explain that covert saccades likely represent the brain's "best guess" of where the head impulse will end. As demonstrated in *Figure 1*, the vHIT detects both overt and covert saccadic movements, which typically coincide with low velocity gains (comparison of head velocity to compensatory eye velocity) for the maneuver that represents the semicircular canal demonstrating hypofunction.

As mentioned earlier, we have three semicircular canals on each side of our head: the horizontal canal, the anterior vertical canal, and the posterior vertical canal. Two of the canals are oriented vertically, while one is oriented horizontally. As shown in *Figure 2*, the three canals are oriented in such a way (90° to each other) so that whether we are tumbling, spinning, rolling, or moving angularly, these canals transduce this information and tell us where we are in space. Being oriented at 90° to each other covers movement in all spatial planes. All the tests of vestibular function that have been used up until now, such as VNG and rotary chair, evaluate horizontal canal function only. This new test, vHIT,

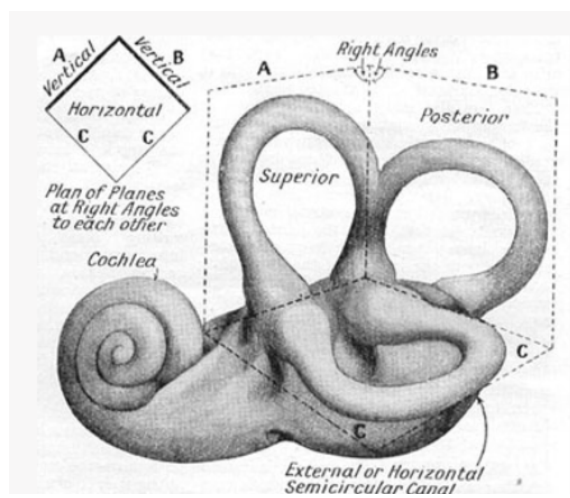

Figure 2*. Two canals are oriented vertically (the anterior vertical and the posterior vertical) and one canal is oriented horizontally. The canals are able to transduce movement in all spatial planes because they are oriented at right angles to each other.*

allows us to test all six canals. Moving the head in the horizontal plane activates or suppresses the right and left horizontal canals depending on direction of head movement. Moving the head in the right anterior – left posterior (RALP) plane at a 45° angle activates or suppresses the right anterior and left posterior vertical canals. Lastly, moving the head in the left anterior – right posterior (LARP) plane at a 45° angle activates or suppresses the left anterior and right posterior vertical canals. Therefore, by moving the head in each of the described planes we are able to activate each canal separately *(Figure 3)*.

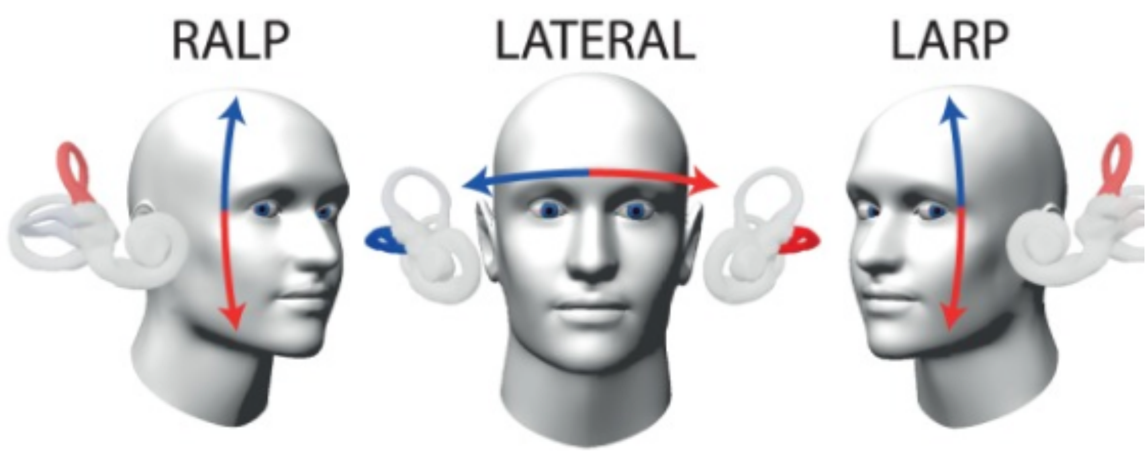

Figure 3. *The horizontal canals are activated during Lateral maneuvers by moving the head in the horizontal plane. Head movement to the right activates the right horizontal canal and suppresses the left horizontal canal, and vise versa. RALP maneuvers activate and suppress the right anterior vertical canal and the left posterior vertical canal by moving the head in the 45° plane shown above. Head movement frontward and downward to the right in the 45° plane activates the right anterior canal and suppresses the left posterior canal. Head movement in the opposite direction (backward and downward to the left) in the same plane activates the left posterior canal and suppresses the right anterior canal. The same movement patterns are consistent for LARP maneuvers in the opposite 45° plane. Image developed by MacDougall, McGarvie, Halmagyl, Curthoys, and Weber, 2013.*

At this time, more normative data exists for lateral maneuvers than for vertical. One reason for this appears to be the added difficulty in performing the right anterior – left posterior (RALP) and left anterior – right posterior (LARP) maneuvers in comparison to the lateral maneuvers. The goal of this study is to collect normative data for vHIT in both horizontal and vertical planes, specifically with the aim to contribute to the development of norms for vertical maneuvers, RALP and LARP. Horizontal data was compared to the gold standard, bithermal water calorics. We will also discuss some of the issues that we encountered as well as some theories as to why our RALP and LARP measures were more variable than lateral measures.

METHODS

Subjects

Nineteen normal hearing young adult subjects (6 males, 13 females) were recruited from classes in the Department of Speech, Language and Hearing Sciences at The University of Arizona. We used the following inclusion criteria: subjects had normal otoscopic findings, defined as clear ear canals (no occlusion) and visible, healthy tympanic membranes. Tympanometric measures demonstrated normal middle ear peak pressure between +50 and -150 mm H_2O in each ear with no perforations. Hearing was screened at 20 dB HL bilaterally for 500, 1000, 2000, 4000, and 8000 Hz. All subjects passed the screening for all frequencies. Normal oculomotor function (gaze, saccades, smooth pursuit, and optokinetic testing). Anyone with a caloric unilateral weakness of greater than or equal to 20% was excluded from this study. Any report of hearing loss, dizziness, or balance difficulties resulted in exclusion from this study.

Instrumentation

Middle ear integrity was evaluated using GSI TympStar®. Hearing was screened in a quiet room using a Maico MA-40 Portable Audiometer with TDH-50 supra-aural headphones. Oculomotor testing and bithermal calorics were tested using Micromedical Visual Eyes 4™ VNG system with ICS NCI-480 water caloric irrigator. vHIT evaluation was performed using Interacoustics EyeSeeCam vHIT system.

Procedures

Participants were informed of the nature of the experiment and participant consent was obtained from each individual. Otoscopy and tympanometry were performed on all participants. Hearing was screened at 20 dB HL at 500, 1000, 2000, 4000, and 8000 Hz. vHIT procedures were conducted prior to oculomotor and caloric procedures. For vHIT testing, participants sat on a height adjustable stool one meter from the wall ahead of them. Stool height was adjusted until eyes aligned horizontally with a blue sticker on the wall. Participants were instructed to keep their eyes fixed on the blue sticker on the wall throughout the test, while relaxing their neck muscles and trying to minimize blinking. The goggle camera was adjusted so the lower eyelid was horizontally aligned with the bottom edge of the camera view. Head and eye movements were calibrated. For lateral maneuvers, the examiner placed her hands along the left and right mandibles below the goggle strap, being careful not to touch the strap or goggles. For RALP and LARP maneuvers, the examiner placed her right hand on top of the head and left hand under the chin. The examiner stood directly behind the participant at 180° azimuth for lateral maneuvers, moving the head 10° - 15° to the right and left in the horizontal plane. The examiner stood behind the participant at 135° azimuth for RALP maneuvers and at 225° azimuth for LARP maneuvers. For both RALP and LARP maneuvers, the participant looked forward at 0° azimuth while rapid, high velocity, short distance head movements were conducted in the appropriate 45° plane. At a later point in the study, a swim cap was employed in an attempt to minimize goggle slippage.

For oculomotor and caloric testing, eye movements were calibrated. During oculomotor testing, participants were instructed not to move their head while following the appropriate target with their eyes during gaze, saccades, smooth pursuit, and optokinetic testing. For calorics, the exam chair was reclined such that participants' head was 30° re: the horizontal plane, to vertically orient horizontal canals. Eyes were covered and water caloric irrigations were performed at 30° C and 44° C in the following order: Left Cool, Right Cool, Left Warm, Right Warm. There was a 5 minute break between each irrigation.

Analysis

vHIT average velocity gains and symmetry comparisons were analyzed for Lateral, RALP, and LARP maneuvers. For Lateral maneuvers, 60 ms instantaneous velocity gain data was compared to 1-100 ms velocity regression data. For RALP and LARP maneuvers, the Interacoustics EyeSeeCam system generates 1-100 ms velocity regression data, but does not generate instantaneous velocity measurements at 40, 60, and 80 ms due to high variability. RALP and LARP measures were compared. The presence or absence of corrective saccades, both overt and covert, was noted.

RESULTS

All participants had clear ear canals and visible tympanic membranes with no perforations. All participants had normal middle ear function and passed a hearing screening at 20 dB HL at octave intervals from 500 – 8000 Hz. For all participants, oculomotor function was normal and caloric asymmetry and directional preponderance were less than 10%. While vHIT gains for vertical measures were more variable, no corrective saccades were observed for lateral or vertical vHIT measures.

vHIT Lateral Maneuvers

The average velocity gain (comparison of head velocity to compensatory eye velocity) was calculated for right lateral and left lateral maneuvers using instantaneous velocity measurements at 40, 60, and 80 ms and using the velocity regression measurement from 1-100 ms. Average instantaneous velocity gains for right lateral maneuvers were 1.334 at 40 ms, 1.175 at 60 ms, and 1.009 at 80 ms. Average velocity regression gain (1-100 ms) for right lateral maneuvers was 1.147. Average instantaneous velocity gains for left lateral maneuvers were 1.271 at 40 ms, 1.159 at 60 ms, and 1.035 at 80 ms. Average velocity regression gain (1-100 ms) for left lateral maneuvers was 1.172. A comparison of 60 ms instantaneous velocity gain to 1-100 ms velocity regression gain is shown in *Figure 4*. Both measurements provided an accurate representation of average velocity gain for lateral maneuvers, as there was no significant difference between the two measurements. The range of velocity gains was 1.03 – 1.51 for right lateral maneuvers and was 1.03 – 1.58 for left lateral maneuvers. The average gain asymmetry between right lateral and left lateral maneuvers was 2.6%, with an asymmetry range of 0% – 14%.

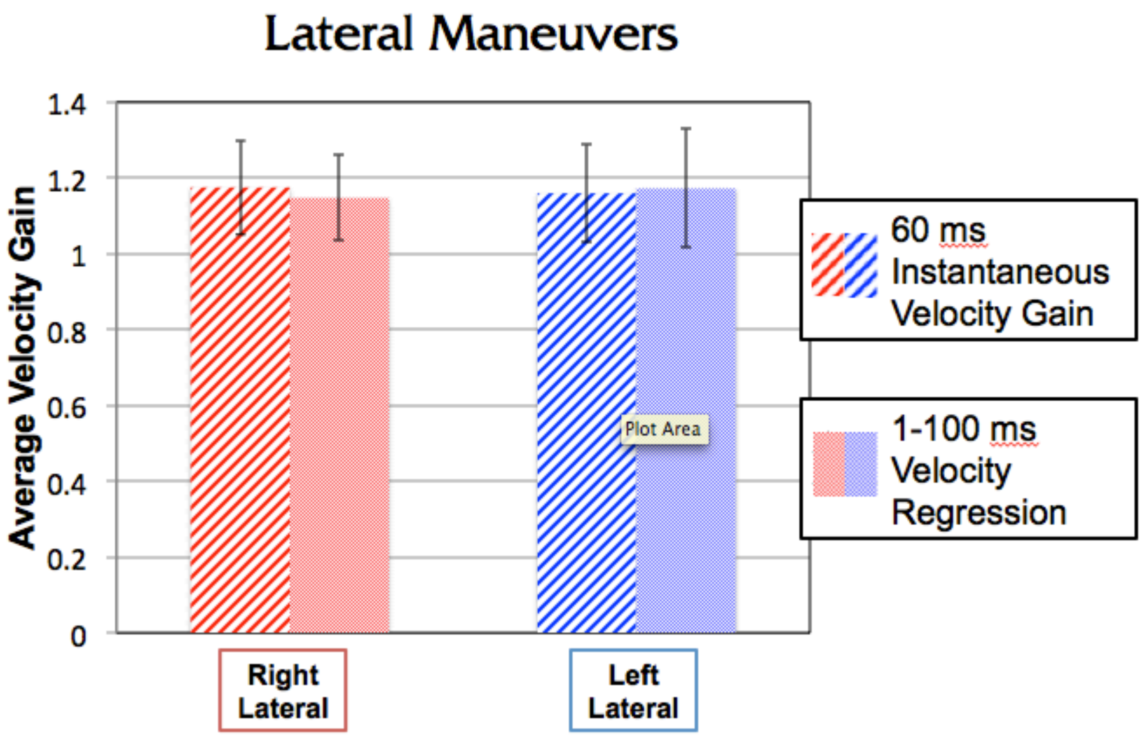

Figure 4. Average velocity gains (comparison of head velocity to compensatory eye velocity) and standard deviations (error bars) are shown for right and left lateral maneuvers. The average instantaneous velocity gain at 60 ms is compared to the average velocity regression gain measured from 0 – 100 ms. Data indicate insignificant differences between instantaneous velocity measurement at 60 ms and velocity regression analysis over 1 – 100 ms, suggesting that either measurement is likely appropriate for reporting average velocity gains for lateral maneuvers.

vHIT RALP and LARP Maneuvers

The average velocity gain (comparison of head velocity to compensatory eye velocity) was calculated for RALP and LARP maneuvers using the velocity regression measurement from 1-100 ms as this is the only measurement provided by the Interacoustics EyeSeeCam system *(Figure 5)*. For RALP, the average velocity regression gain (1-100 ms) was 1.514 for right anterior maneuvers and was 1.665 for left posterior maneuvers. For LARP, the average velocity regression gain (1-100 ms) was 0.923 for left anterior maneuvers and was 0.876 for right posterior maneuvers. A 2-tailed t-test was used to determine if RALP average velocity gains were significantly different from LARP average velocity gains. The t-test returned a t-statistic of 9.597, $p<0.000$, indicating that the difference in average velocity gains between RALP and LARP were statistically significant. For RALP, the range of velocity gains was 1.12 – 2.11 for right anterior maneuvers and was 1.08 – 2.29 for left posterior maneuvers. The average gain asymmetry between right anterior and left posterior (RALP) maneuvers was 7.26%, with an asymmetry range of 0% – 16%. For LARP, the range of velocity gains was 0.52 – 1.23 for left anterior maneuvers and was 0.54 – 1.10 for right posterior maneuvers. The average gain asymmetry between left anterior and right posterior (LARP) maneuvers was 7.11%, with an asymmetry range of 0% – 21%.

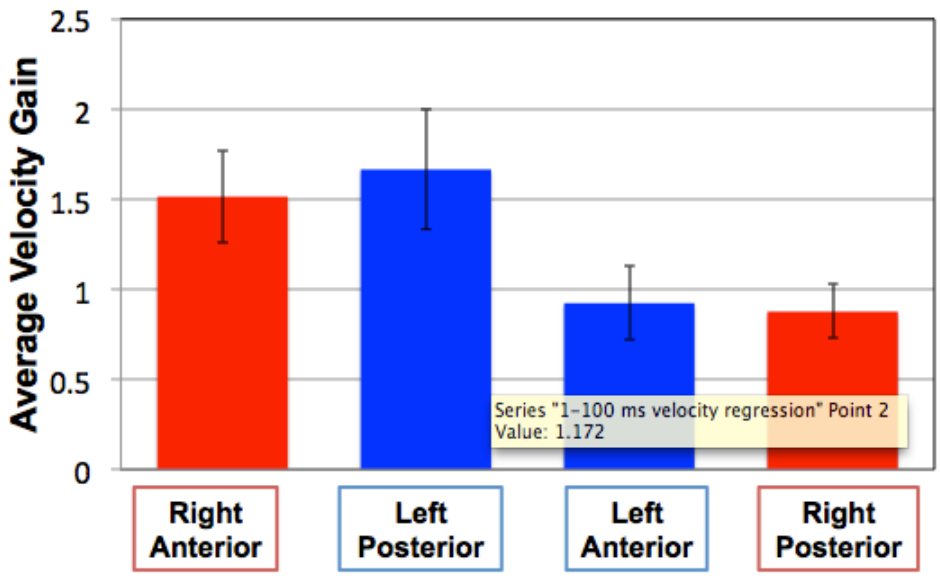

Figure 5. *Average velocity gains (comparison of head velocity to compensatory eye velocity) and standard deviations (error bars) are shown for RALP and LARP measurements. A two-tailed t-test returned a t-statistic of 9.597 and a p-value of <0.000, indicating that RALP average velocity gains were significantly higher than LARP average velocity gains.*

DISCUSSION

Ranges of asymmetry and ranges of velocity gain were reported for Lateral, RALP, and LARP maneuvers. However, there are no established criteria for when a measure of asymmetry is to be considered abnormal. Similarly, we lack an agreed upon criteria that determines when a low gain of head velocity compared to compensatory eye velocity is indicative of canal hypofunction. Based on discussion with other professionals in the field of audiology, the guideline currently in use is that a gain of less than 0.8 is considered abnormal for lateral maneuvers and a gain of less than 0.7 is considered abnormal for vertical maneuvers.

As mentioned earlier, the average velocity gains for RALP maneuvers were significantly higher than average velocity gains for LARP. This significant difference appears to be related to the physical characteristics of the Interacoustics EyeSeeCam goggles *(Figure 6)*. The goggles are small and are fixed in place with an adjustable strap that runs above the ears and behind the head. The goggles are to be worn tightly so the plastic rims that surround the eye sit firmly in the orbital socket. A camera is attached to the goggles above either the right or left eye. Although the goggles are lightweight, the attached camera is heavier due to the required technology it encases. When the head is moved quickly at a high velocity, inertia causes the camera to lag behind the initial goggle movement before catching up again. Throughout this discussion, we will refer to this effect as "slippage." This slippage effect appears to be enhanced during vertical maneuvers because the camera rocks front to back more easily than side to side. Slippage can also be seen when the goggle strap slips on the participant's hair, resulting in high gains because it appears as if the eye is preceding or mirroring the head movement.

Figure 6. *Interacoustics EyeSeeCam vHIT System goggles and lenses are lightweight, but the camera attached above the right or left eye is heavy, often causing camera slippage. When the head is quickly accelerated, inertia can cause the camera to lag behind initial goggle movement, resulting in high eye velocities and high gains.*

The inertia of the camera appears to have a more significant effect on RALP when the camera is located above the right eye, and a more significant effect on LARP when the camera is located over the left eye. This difference is a result of the angle of head movement in relation to the camera mass. When a RALP maneuver is being performed, the right eye acts almost as a pivot point for the head's rotation. Similarly, the left eye is closely aligned with head movement along the plane used in LARP maneuvers. Throughout the duration of this study, the camera was positioned over the right eye for all Lateral, RALP, and LARP maneuvers, resulting in significantly high average velocity gains for RALP. One suggestion would be to position the camera over the left eye for RALP maneuvers and then reposition the camera over the right eye for LARP maneuvers, which would provide normal, comparable gains for both RALP and LARP. While this solution is plausible, one of the strengths of this new test is that it requires only 10-15 minutes to administer. Repositioning the camera would require recalibration of both eye and head movements, taking additional time.

Due to our consistent slippage concerns, we tried using a swim cap in an attempt to mediate this problem. Initial testing with a swim cap resulted in an impression of more control during vertical maneuvers and less slippage from hair, but results were similar in terms of variability. Ideally, Interacoustics will continue to improve their product and make the necessary adjustments to mediate this issue related to slippage and camera location.

During this study, we encountered additional concerns that warrant discussion. There is limited eye travel for vertical maneuvers compared to lateral maneuvers, resulting in more variable results. One participant reported that the ceiling light was reflecting off of the goggle lenses during vertical maneuvers, interfering with her ability to keep her eyes focused on the target sticker. Wandering attention was also a problem at times. A few results demonstrated shaky eye movements, indicating that the camera software was unable to maintain cursor position on the curvature of the pupil. There are several possible reasons we may see shaky eye movements, including a software issue, the chance that a subject may lose the target due to a high degree of movement (excursion greater than 10° - 15°), or if the pupil for any reason moves outside of the range of the camera's view.

CONCLUSION

In general, lateral maneuvers are easy to perform and results are consistent. Vertical maneuvers, however, are difficult to perform and results are more variable, which is one of the main reasons vertical measures are not being used as often in the clinic compared to lateral measures. Inconsistent average velocity gain measurements for vertical maneuvers suggests that presence or absence of corrective saccades may in fact be a better indicator of normal versus abnormal results, rather than relying on average velocity gain measurements that we know to be highly variable. Additionally, the obstacles we encountered in terms of camera slippage and inconsistent RALP and LARP gain measurements may be idiosyncratic to our instrumentation (Interacoustics EyeSeeCam vHIT system). Therefore, it is likely that comparing normative data among various vHIT systems may not be appropriate, especially normative velocity gain data. This test is valuable as it is the first test that allows us to clinically evaluate all six semicircular canals individually, but consistent techniques, normative data, and training methods for professionals are needed in order for vertical measures to be used consistently in patient care.

FUTURE RESEARCH

Although I originally set out to collect normative data for the vHIT, my research led to additional, unexpected findings. I expected to see consistent results while testing normal, healthy, and young participants, but I soon discovered this was not the case. For my first handful of participants, I was still adjusting my technique and determining exactly how many maneuvers I needed complete in order to collect data that sufficiently represented each participant's SCC function. After running six or seven participants, Cammy Bahner, M.S. (audiologist with Interacoustics) provided me with some "tips" for dealing with camera slippage concerns and suggested that we focus more on the presence or absence of corrective saccades instead of average velocity gain. She also suggested that I try slowing the head movement velocities to around 150 degrees per second because it may help prevent extensive camera slippage. For my next few participants I tried slowing down the velocity of the head movements as suggested, while making sure to never go below 100 degrees per second. Slower head velocities helped reduce RALP gain only slightly, and only for one or two participants. By the time I was testing the second half of my participants, I had a much better understanding of the limitations and shortcomings of the instrumentation and was much more confident in the consistency of my technique. As I became more proficient with the Interacoustics vHIT system, I began to recognize procedural problems that would prevent me from truly collecting normative data in regards to gain measurements that could be compared to results from other systems (Otometrics, Micromedical), specifically related to the problem of camera slippage. Therefore, I recommend that another student continue this research with the following changes.

Be very consistent with the technique being used. Before beginning data collection, be comfortable and proficient with the hand placements and techniques selected by the investigator. To account for the effect of camera location on the camera slippage problem, I recommend completing RALP and LARP maneuvers with the camera attached above the right eye, and then re-calibrating and repeating RALP and LARP maneuvers with the camera attached above the left eye. Collecting RALP and LARP results using both camera locations will allow for additional statistical analyses, will provide a more extensive representation of normal vertical measures, and will help determine whether or not a corrective value could be used to account for camera slippage. Comparing camera-right versus camera-left results for each individual participant may aid in confirming that the variability in average velocity gains for vertical maneuvers is idiosyncratic to our instrumentation. If this is the case, normative data for each vHIT system will need to be collected separately. This research will also provide insight as to which measurement, presence/absence of saccades or average velocity gain, should be the gold standard as to determining when a vHIT result should be classified as abnormal.

References

Barin, K. (2016). Background and technique of caloric testing. In G. P. Jacobson & N. T. Shepard (Eds.), *Balance function assessment and management* (2nd ed.), (283-317). San Diego, CA: Plural Publishing.

Curthoys, I. S., MacDougall, H. G., McGarvie, L. A., Weber, K. P., Szmulewicz, D., Manzari, L., Burgess, A. M., & Halmagyi, G. M. (2016). The video head impulse test (vHIT). In G. P. Jacobson & N. T. Shepard (Eds.), *Balance function assessment and management* (2nd ed.), (391-430). San Diego, CA: Plural Publishing.

MacDougall, H. G., McGarvie, L. A., Halmagyi, G. M., Curthoys, I. S., & Weber, K. P. (2013). Application of the video head impulse test to detect vertical semicircular canal dysfunction. *Otology & Neurotology, 34*(6), 974-979.

MacDougall, H. G., McGarvie, L. A., Halmagyi, G. M., Curthoys, I. S., & Weber, K. P. (2013). The video head impulse test (vHIT) detects vertical semicircular canal dysfunction. *Plos One, 8*(4), e61488.

Matiño-Soler, E., Esteller-More, E., Martin-Sanchez, J., Martinez-Sanchez, J., & Perez-Fernandez, N. (2014). Normative data on angular vestibulo-ocular responses in the yaw axis measured using the video head impulse test. *Otology & Neurotology, 36*(3), 466-471.

McCaslin, D. L., & Jacobson, G. P. (2009). Current role of the videonystagmography examination in the context of the multidimensional balance function test battery. *Seminars in Hearing, 30*(4), 242-252.

McCaslin, D. L., Jacobson, G. P., Bennett, M. L., Gruenwald, J. M., & Green, A. P. (2014). Predictive properties of the video head impulse test: Measures of caloric symmetry and self-report dizziness handicap. *Ear and Hearing, 35*(5), e185-e191.

McGarvie, L., MacDougall, H., Halmagyi, G., Burgess, A., Weber, K., & Curthoys, I. (2015). The video head impulse test (vHIT) of semicircular canal function - age-dependent normative values of VOR gain in healthy subjects. *Frontiers in Neurology, 6*, 154.

Murnane, O., Mabrey, H., Pearson, A., Byrd, S., & Akin, F. (2014). Normative data and test-retest reliability of the SYNAPSYS video head impulse test. *Journal of the American Academy of Audiology, 25*(3), 244-252.