White Paper - Testing Vertical Head Impulses with EyeSeeCam

Pilot Study completed by the Interacoustics Clinical Research Team

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Introduction

The video head impulse test (vHIT) is now widely used to quantify vestibulo-ocular reflex (VOR) function in patients with dizziness or vertigo (Halmagyi et al 2017). The function of the horizontal VOR can be easily assessed with both search coil and vHIT by rapidly rotating the head in yaw and measuring the resulting eye movement in the same direction (Bartl et al 2009, MacDougall et al 2009). For assessing the function of the vertical semicircular canals, however, the scientific literature introduced a multitude of protocols with different head rotation planes and different initial orientations of the head, as well as gaze direction. Either the head is rotated separately in the pitch and roll planes (Glasauer et al 2004) or, more commonly, it is rotated in the planes of the semicircular canals. More precisely, the head is rotated right-downward to left-upward in the plane of the right anterior and left posterior canals (RALP) or left downward to right-upward in the plane of the left anterior and right posterior canals (LARP). The standard protocol in the three-dimensional (3D) search coil is with the head straight and with the visual target placed straight ahead (Aw et al 1996). In this setup, VOR gain is calculated as the ratio of 3D eye and 3D head velocity. The suggested protocol for 2D search coil (Migliaccio and Cremer 2011) and 2D pupil-based video-oculography (VOG) (MacDougall et al 2013), which both lack the ability to measure torsion, is with the head turned to the right (LARP) or to the left (RALP) and with the visual target placed straight ahead. In this protocol, the gaze-in-head assumes an eccentric direction that is approximately aligned with the plane of the tested canals (RALP or LARP). As a result, the eye moves primarily in the tested canal plane with negligible torsional movements around the line of sight. Thus, a 3D measurement becomes unnecessary; it is sufficient to calculate VOR gain as the ratio of 2D eye velocity and head velocity around an axis that is perpendicular to the canal plane.

The purpose of the angular VOR is to stabilize gaze on a visual target when the head rotates. It does so by instantaneously rotating the eye at the same velocity but in the opposite direction of the head rotation. As head rotations can occur around any head-fixed 3D axis, so must the VOR be able to counter-rotate the eye, ideally around the same 3D axis in order to stabilize gaze on target. Unlike slow VOR responses to, e.g., caloric stimulation, which show a dependency on gaze direction, rapid VOR responses to head impulses counter-rotate the eyes in a head-fixed 3D coordinate system independently of gaze (see Glasauer 2007 for review).

McGarvie and colleagues (2015) have shown with the ICS Impulse vHIT system that “gaze direction has a major effect on the measured VOR” (Halmagyi et al 2017). For vertical impulses, the measured gain of the rapid VOR was lower if gaze direction was not aligned with the plane of the canals. Therefore, the measurement of the VOR with gaze straight-ahead was termed “incorrect” (Halmagyi et al 2017) and the recommendation was to use the protocol that is adopted by ICS Impulse (MacDougall et al 2013).

On the other hand, the preferred method for EyeSeeCam recommends using the straight gaze for vertical impulse, just as in the 3D search coil setup. The eye movement analysis in the EyeSeeCam system is based on the fact that the 3D axis of eye rotation is head-fixed and that it can be treated as a rotation vector, which can be separated into its horizontal, vertical, and torsional components (Crawford and Vilis 1991).

We set up a study to verify McGarvie et al's finding using ESC. But first, a few observations about the paper itself:

1. Only LARP impulses were studied.
2. It is unclear if the ICS Impulse was used in the study. The body of the paper implies that it was but the abstract says a prototype device was used.
3. The paper states that although the apparent gain was reduced significantly, no catch-up saccades were observed. **This is a really important observation because it means that the eyes remain on the target despite the apparently lower gain.** One reason the authors offer is that the torsional eye movements cause the impulse to look delayed as in the bottom tracings of Figure 2B. However, in the bottom tracings of Figure 2A, the eye movements actually look smaller than the head movements regardless of the delay. That makes the results of the study hard to explain. The logical conclusion is that something else is responsible for the discrepancy.

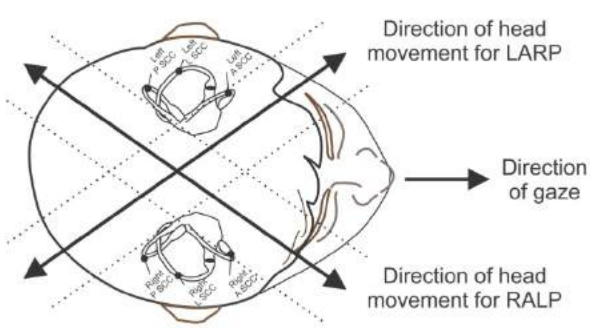
While the reason for the delay remains an open question that eventually might be explained by differences between the used prototype device and the validated ICS impulse, the missing catch-up saccades confirms and can be explained by the above considerations on VOR physiology and vector algebra. During LARP and RALP testing, the head rotation around the vertical axis is the only component that, without a fully functional VOR, would displace the eyes away from the target. In contrast, the torsional movement component around the line of sight evidently does not change the eye position with respect to that target. The VOR transduces the effective vertical component of head rotation into an equal and oppositely directed vertical component of eye rotation, such that the eye remains on target. Therefore, the EyeSeeCam system uses just the vertical eye and head velocity components to calculate VOR gain. Their ratio is 1 if the VOR is fully functional. In contrast, McGarvie et al did not use just the vertical component of the head rotation. While their method is correct for the gaze directed eccentrically along the plane of the tested canal, it results in a low gain if the gaze is directed along the mid-sagittal plane. Therefore, their results are not applicable to the algorithm that is implemented in the EyeSeeCam system.

We set up a pilot study to determine the effect of gaze direction on VOR gain during vertical head impulse testing.

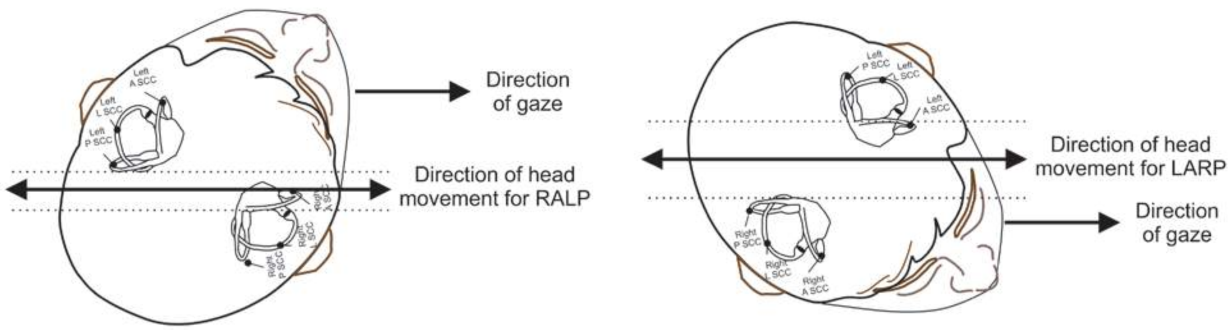
<u>Method</u>

Three different protocols were tested:

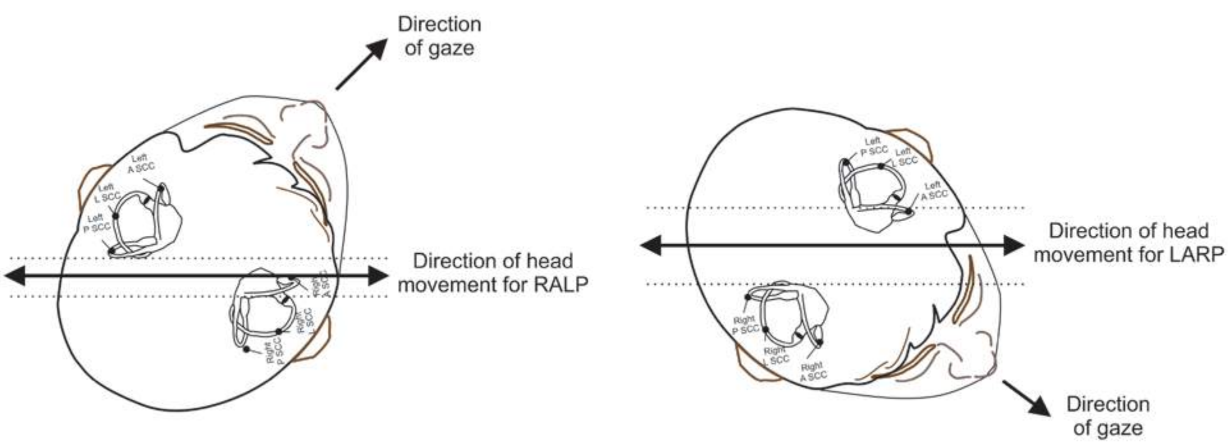
Protocol 1 – ESC standard protocol with the head straight and moving right-downward to left-upward (RALP) or left-downward to right-upward (LARP) with the target placed straight ahead.



Protocol 2 – ICS standard protocol with the head turned right (LARP) or left (RALP) and moving forward or backward. The target is placed straight ahead.



Protocol 3 – Modified ICS protocol with the head moving as in protocol 2 but the target placed at straight ahead gaze about 45 degrees.



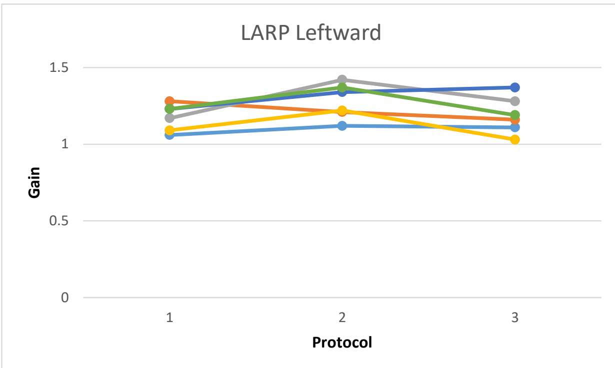
Six subjects were tested in the following order:

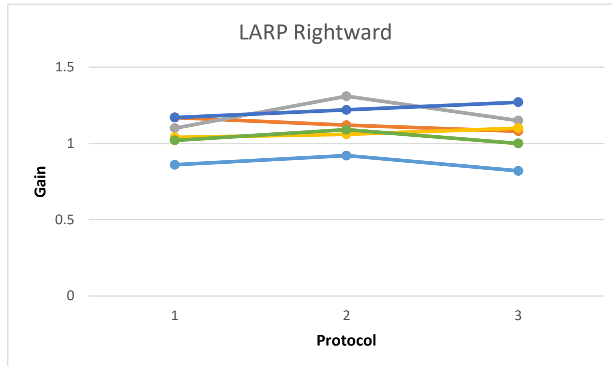
Subject 1: Protocol 1, Protocol 2, Protocol 3
Subject 2: Protocol 1, Protocol 3, Protocol 2
Subject 3: Protocol 2, Protocol 1, Protocol 3
Subject 4: Protocol 2, Protocol 3, Protocol 1
Subject 5: Protocol 3, Protocol 1, Protocol 2
Subject 6: Protocol 3, Protocol 2 Protocol 1

The same examiner was used for all tests. Minimum of 7 impulses were performed for each direction.

Results

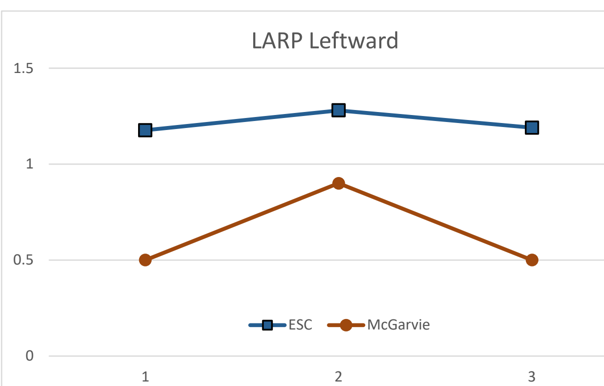
The LARP VOR gains for each subject for the different protocols are shown below.

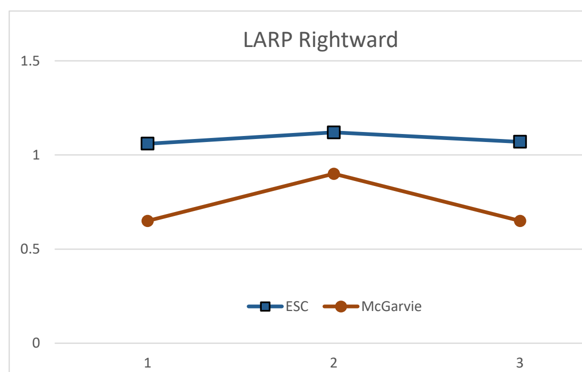




The statistics show that there is no significant difference in gain values between the different protocols. There is a gain difference for direction with the gain for leftward impulses being slightly higher than the gain for rightward impulses. This asymmetry has been noted with coil measurements as well and is most likely related to which eye is used for recording of the responses (Weber et al., 2008). The Figure below compares the mean VOR gain from McGarvie et al with our study of ESC:

The results for RALP are similar.





Discussion

Our findings do not support the results from McGarvie et al (2015). The gain for the the standard EyeSeeCam protocol (protocol 1) are not significantly lower than the protocol where the gaze is in the plane of the tested canals.

Conclusion

From this pilot study we were able to show that the gains are not statistically different when testing the vertical canals in any of the 3 protocols (different head and eye positions) that are typically used for vHIT. We did not show reduced gain as McGarvie et al.'s paper claimed would occur if the eyes were not directed in the plane of the tested canals. This pilot study suggests that EyeSeeCam is providing accurate gain results when tested according to the standard protocol. We cannot explain the discrepancy at this time. A larger follow-up study is needed to better understand the differences.

References

Aw ST, Haslwanter T, Halmagyi GM, Curthoys IS, Yavor RA, Todd MJ (1996) Three-dimensional vector analysis of the human vestibuloocular reflex in response to high-acceleration head rotations. I. Responses in normal subjects. J Neurophysiol 76:4009-4020.

Bartl K, Lehnen N, Kohlbecher S, Schneider E (2009) Head impulse testing using video-oculography. Ann N Y Acad Sci 1164:331–333. https://doi.org/10.1111/j.1749-6632.2009.03850.x

Crawford JD, Vilis T (1991) Axes of eye rotation and Listing's law during rotations of the head. J Neurophysiol 65:407-423

Glasauer S, von Lindeiner H, Siebold C, Büttner U (2004) Vertical vestibular responses to head impulses are symmetric in downbeat nystagmus. Neurology 63:621-625

Glasauer S (2007) Current models of the ocular motor system. Dev Ophthalmol 40:158-174

Halmagyi GM, Chen L, MacDougall HG, Weber KP, McGarvie LA, Curthoys IS (2017) The Video Head Impulse Test. Front Neurol 8:258. https://doi.org/10.3389/fneur.2017.00258

MacDougall HG, Weber KP, McGarvie LA, Halmagyi GM, Curthoys IS (2009) The video head impulse test: diagnostic accuracy in peripheral vestibulopathy. Neurology 73:1134–1141

Migliaccio AA, Cremer PD (2011) The 2D modified head impulse test: a 2D technique for measuring function in all six semi-circular canals. J Vestib Res 21:227-234

Macdougall HG, McGarvie LA, Halmagyi GM, Curthoys IS, Weber KP (2013) The video Head Impulse Test (vHIT) detects vertical semicircular canal dysfunction. PLoS One 8:e61488

Weber KP, Aw ST, Todd MJ, McGarvie LA, Pratap S, Curthoys IS, Halmagyi GM (2008) Inter-ocular differences of the horizontal vestibulo-ocular reflex during impulsive testing. Prog Brain Res; 171:195-8.