1. Let’s start with: ‘What is an oculomotor assessment’?

Oculomotor means eye movement, so an oculomotor assessment refers to the process of measuring how and when a person’s eyes move in response to light, moving objects and head motion. Eye movements facilitate the clear vision stabilizing images on the retina, particularly against head and body movements, capturing and keeping specific stimuli on the fovea and aligning the retinal images in the two eyes to ensure single and binocular vision (Rodríguez-Labrada, Vázquez-Mojena & Velázquez-Pérez, 2019).

2. What are the different types of eye movements that can be assessed in the clinical setting?

Eye movements can be voluntary, although most eye movements occur through reflexes in response to changes in head position. Six types of eye movements are traditionally included in the clinical test battery namely:

- Gaze holding
- VOR (Vestibulo-ocular reflex)
- OKR (Optokinetic reflex)
- Smooth pursuit
- Saccades
- Vergence

3. What would a patient with oculomotor impairments commonly complain of in the clinical setting?

Patients typically complain of blurred vision, diplopia (double vision), impaired eye movements, difficulty in reading, dizziness, headaches, ocular pain, and poor visual-based concentration.

4. A lot of clinicians only access oculomotor function manually as a bedside assessment. How important is it to use VNG or Impulse equipment?

When there are no objective tools available, subjective assessment is better than not conducting any assessment, but it is much easier to miss pathology e.g. if you are evaluating saccades you won’t be able to express the results in terms of accuracy, latency, and velocity. You could consider a bedside assessment as a screening procedure and assessment using VNG or Impulse equipment as more diagnostic. Also, if you want to refer back to the results or ask for a second opinion or even for medicolegal purposes the objective recorded results are invaluable. We use the ICS Impulse and ICS ChartR VNG systems.

5. Can you tell us more about the ICS Impulse and ICS ChartR VNG systems?

Sure, the *ICS Impulse* is a lightweight/low mass goggle that uses a high-speed USB camera to measure eye and head movements, originally designed for video head impulse testing. After further development, however, it is a complete and customizable balance testing solution. Currently, the system includes the following modules as options:

- Video Frenzel
- vHIT
- Gaze
- Positional static
- Positional dynamic: Dix-Hallpike
- Oculomotor: Saccades, VVOR (visually enhanced vestibulo-ocular reflex), VORS (video-ocular reflex suppression)
- Caloric

The *ICS ChartR VNG* is a complete videonystagmograhy testing solution that is considered a standard part of a balanced assessment. VNG offers a way to directly measure eye movement by tracking the pupil using infrared video technology to record a patient's eye movements including a type of involuntary eye movement called nystagmus. The ICS VNG system offers a complete test battery including:

- Saccades
- Gaze
- Positional static
- Positional dynamic: Dix-Hallpike
- Oculomotor: Saccades, Pursuit, Optokinetic
- Caloric

6. What tests do we use to evaluate the oculomotor system with the ICS systems and how does the test battery differ between the two systems?

The biggest difference between the two systems is that the ICS impulse only allows for monocular recording of eye movements versus the VNG system which allows for the recording of both eyes. The additional differences are listed below but will also be described in the advantages and disadvantages of using the ICS impulse system, discussed in proceeding questions and answers lower down.

ICS ChartR VNG System	ICS Impulse System
Binocular recording	Monocular recording
Heavy goggles	Lightweight goggles
Stationary equipment	Potable equipment
Set protocol	Modular (tests can be added as the clinic's needs grow)
Protocol only assesses the central vestibular system	The protocol allows for the assessment of both central and peripheral vestibular system
Video images of the eye cannot be played back in slow motion	Slow-motion playback of video image
Normative data have been established for all testing protocols	Normative data has not yet been established for VORS and VVOR tests
Speed of eye movements for tracking is guided by the movement of a dot on a lightbar (consistent velocity of eye movements is elicited across different tests)	Speed of eye movements for VORS is guided by the speed at which the clinician moves the head (may not be as consistent unless a metronome is used)
Optokinetic test is part of the testing protocol, however, because it does not involve the patient's full visual field, it is often more a reflection response from the tracking system and not a true optokinetic response.	Optokinetic test must be done manually – however, when done correctly, a true optokinetic response can be elicited

Table 1. Differences between the ICS ChartR VNG System and the ICS Impulse System.

Both systems can assess the oculomotor system. The specific tests forming part of each system are specified below in the table:

ICS ChartR VNG System	ICS Impulse System
Saccades (Binocular)	Saccades (Monocular)
Optokinetic (Part of protocol)	Optokinetic (Performed manually)
Tracking / Pursuit	Vestibulo-ocular reflex suppression (VORS)
	Visually enhanced vestibulo-ocular reflex (VVOR)

Table 2. Specific tests for the ICS ChartR VNG System and the ICS Impulse System.

7. When would you perform an oculomotor assessment?

We perform it in every patient that complains of dizziness or imbalance. If you work with children, you should also assess if they present with reading problems. The clinical assessment of oculomotor function can help to differentiate diagnosis as well as providing useful biomarkers for the understanding of disease physiopathology and progression.

8. Why is it important to conduct an oculomotor assessment?

Oculomotor tests are essential to detect central impairment of the oculomotor system and/or vestibular ocular system. Oculomotor Dysfunction is a common vision problem and occurs in people of all ages, both children and adults. Oculomotor Dysfunction (OMD), also known as Ocular Motility Dysfunction, affects reading, sports, balance, depth perception as well as most visually related tasks. Eye movements are a valuable source of information to the clinician as abnormalities frequently act as clues to the localization of a disease process. During the assessment, the clinician can detect subtle ocular motility abnormalities reflecting the effect of the balance disorder on the ocular system due to its intricate connections with the vestibular apparatus (Antoniades & Kennard, 2015).

9. What about concussions? Can they directly impair oculomotor function?

Yes definitely. Ocular issues (poor eye tracking) after a concussion are common. Specifically, cranial nerves (CN) III, IV and VI which innervate the eye muscles are susceptible to injury anywhere along the route from the brainstem to eye muscles, so this needs to be assessed. This also highlights the importance of a cranial nerve assessment as part of the balance evaluation.

10. What is the most common oculomotor abnormality observed in patients with dizziness?

Spontaneous nystagmus is the most common observed abnormality. Oculomotor abnormalities are also common in neurodegenerative disorders.

11. Can you refresh my memory regarding the Saccade pathway?

To make this easier I am going to also refer to the diagram below:

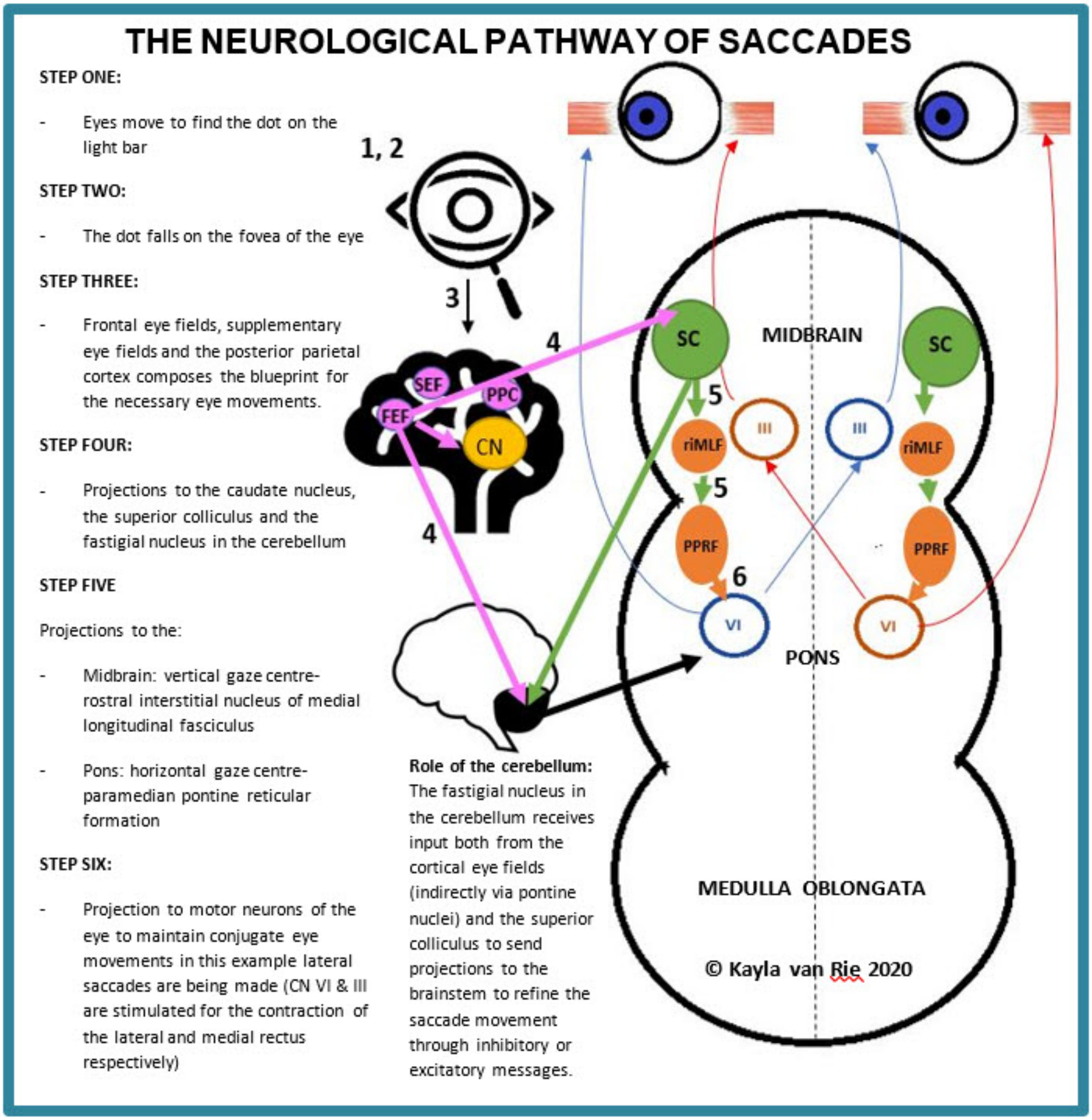

Figure 1. The neurological pathway of saccades.

First, let's have a look at the purple ovals on the diagram: So once the patient's eyes have found the point of interest (the dot), the neural command for the saccade movement appears to be mainly refined within the frontal eye field of the cortex. The supplementary eye fields in the frontal cortex and the posterior parietal cortex also supplement the information processed in the frontal eye fields. The information supplemented by the posterior parietal cortex plays an important role in assisting the patient in focusing attention on the dot.

Efferent projections are then sent to the yellow and green colored shapes, namely, the caudate nucleus and the superior colliculus. The caudate nucleus integrates spatial information with motor behavior formulation, whilst the superior colliculus plays a role in the orientation of the head and eyes and further processes information from the retina.

If you follow the arrows going from the superior colliculus it extends to two orange ovals. One is the midbrain's vertical gaze center and the other is pons' horizontal gaze center (Also known as the rostral interstitial nucleus of medial longitudinal fasciculus and the paramedian pontine reticular formation, respectively).

These structures, in turn, send messages to the neurons controlling eye muscles and to produce conjugate eye movements, which means symmetrical eye movements, and a saccade is produced.

For example, if you are testing horizontal saccades, the abducens nerve will be stimulated to contract/relax the lateral rectus and the oculomotor nerve will be stimulated to contract/relax the medial rectus.

It is also important to understand that the cerebellum is also involved in the coordination of visually guided saccade production. The fastigial nucleus in the cerebellum receives input both from the cortical eye fields (indirectly via pontine nuclei) and the superior colliculus to send projections to refine the saccade movement through inhibitory or excitatory messages.

So, as you can see, understanding the pathway and the function of each anatomical site can help us be more specific about possible pathology location.

12. How do you perform the test for Saccades?

On the VNG system, you would ask the patient to look at the lightbar. The clinician would tell them that a red dot will appear and that this dot is going to jump to different locations on the light bar. The patient is then instructed to keep their gaze on the dot and to follow the dot once it has jumped to a different location. It is important to tell the patient to not anticipate the movement of the dot and to only move their eyes once the dot has changed location.

With the ICS Impulse system, the instructions remain the same, the only difference is that the dot does not appear on a light bar, but rather, projects from the goggles onto the wall.

Before the test is done, you must perform the calibration. If the calibration is incorrect, the results may reflect abnormality which is due to equipment inaccuracy and not pathology.

The saccade test should be run for around 1 minute 42 seconds. While the test is running it is important to also look at the recording of the eyes to ensure that the cross hair is accurately following the pupil and that the patient is not anticipating the dot moving. It is also important to ensure that the patient is following instructions correctly and not excessively blinking and lastly. Looking at the recording of the eyes also enables the clinician to visually observe the consistent catch-up saccades made when there is pathology.

Once the test is completed, it is important to look at how many recordings were accepted. If less than 80% were accepted, it is recommended to run the test again as there could have been too much artifact (e.g.: blinking or an unstable crosshair)

13. Which parameters are important to record during Saccade testing?

On both the ICS impulse and VNG systems, once the test has been completed, you will see that the results are presented to you with three scatter plots, namely, accuracy, latency, and velocity.

- Accuracy refers to the size of excursion compared with target excursion, measured in percentage.
- Latency relates to the reaction time or time between target movement and first eye movement, measured in ms.
- Velocity implies the actual speed of the eye movement and is measured in deg/sec.

It is vital to analyze if the results fall within normal limits for all three parameters. This is diagnostically important because each parameter is affected by varying factors and pathologies. For example, abnormal accuracy is often related to cerebellar disorders, whereas abnormal latency can be related to age or midbrain pathologies.

14. What is the main difference between saccades and smooth pursuit?

In terms of everyday function, saccades are required when you want to shift your gaze to a stationary object, whereas tracking is used when you are wanting to follow a moving object.

Saccades are a much faster eye movement than tracking and can make voluntarily or reflexively. Tracking, however, is only made voluntarily. Interestingly, it's almost impossible to track an object if there is no moving object to track. If you try to make a tracking like movement without an object to follow, your eyes will make a saccadic movement! Give it a try!

The neurological pathways also differ for the two movements- because saccades are so much faster, the motor plan and coordination require an internal feedback loop, whereas, with tracking, the brain uses visual feedback to produced accurate eye movements (Gaymard & Pierrot-Deseilligny, 1999).

15. What is VVOR?

VVOR stands for visually enhanced vestibular-ocular reflex. It is a test of visual vestibular interaction and is thought to have input from the tracking, optokinetic and central vestibular ocular reflex systems. While doing this test, the patient is required to gaze at a stationary dot while the clinician moves their head at around 0.5Hz.

The VVORs main purpose is gaze stabilization during natural activities such as walking or running. Normal VVOR allows you to e.g. read something while driving or having clear focus while walking in a shopping center and being able to read the SALE sign (which of course could be very important ha-ha).

16. What is VORS?

VORS stands for vestibular ocular reflex suppression. When conducting this test, the clinician again moves the head from side to side at 0.5 hertz with an amplitude of 10 degrees. In this assessment, the instructions to the patients vary from the VVOR assessments. Instead of staring at a dot on the wall, the clinician will ask the patient to focus on a laser dot which is beaming from the impulse goggles. When the head is moved, the laser dot moves with the head thus requiring the patient's eyes to move in the same direction as the head movements.

To achieve this, the tracking neurological pathway is said to inhibit the vestibular ocular reflex. So, the results of the VVOR test should correlate with the tracking results observed in VNG testing.

17. Is there a relationship between smooth pursuit, optokinetic and VVOR results?

I think it is important to mention that we are now moving beyond the scope of the audiologist into the field of neurology. But in summary what I do know is that in patients with most types of genetically identified hereditary spinocerebellar ataxia, SP and OKR gains are low, but VVOR can be normal. In contrast, patients with bilateral vestibulopathy have normal SP and OKR gains, but have, by definition, low VOR resulting in abnormal VVOR. However, patients with impaired SP and OKR, usually due to cerebellar ataxia, produce a near-normal VVOR using their VOR. Similarly, patients with bilateral vestibulopathy produce a near-normal VVOR below ~1 Hz using their SP and OKR systems. Impairment of the VVOR below ~1 Hz, therefore, indicates double pathology, involving both vestibular and cerebellar pathways.

18. Just for clarity – do you consider Smooth pursuit and VORS interchangeable as part of the test battery?

Yes- these two assessments do assess the same neurological pathways. For example, I had a case the other day wherein the bedside evaluation, tracking appeared perfectly normal, however, results were abnormal across frequencies on the VNG software. I then conducted the VORS test and the results were perfectly normal. Turns out this patient just so desperately wanted to identify what was wrong with her that she intentionally was not following the dot accurately in tracking. If I did not have VORS, I would not have been able to objectively comment on the tracking pathways due to poor patient compliance.

When conducting the VORS test over the VNG tracking test, however, the tester does need to ensure that the speed at which he/she is moving the head is accurate and they need to have experience in analyzing the result because the results are not compared to normative data, but rather the clinician needs to analyze the pattern of the head and eye movements to identify possible pathology (which could leave more room for error).

19. What are the advantages of using the ICS Impulse compared to the ICS ChartR VNG?

First, the ICS Impulse System is portable. All that is required for the assessments are the impulse goggles and your laptop. Unlike the VNG system, there is no light bar or no piece of equipment which the goggles need to attach to. The goggles connect straight to your laptop via USB. This fact is highly convenient and progressive, specifically when considering the vestibular population who are often sickly, in the hospital or sometimes so debilitatingly dizzy that they cannot move to get to you. We understand that the best time to assess patients is when they are symptomatic. However, specifically with peripheral or fluctuating pathologies, we often end up needing to assess these patients when they are either asymptomatic or in their less acute stages where central compensation may have already started occurring. This makes it more difficult to elicit diagnostic signs. Imagine being able to get in your car and go see your patient wherever and whenever need be. The immobile VNG system has not allowed us to do this in the past.

Second, the ICS Impulse System enables the clinician to assess the same central pathways as the VNG system. Over and above this, it also enables the clinician to assess the peripheral vestibular system gaining invaluable information on the functioning of all three semi-circular canals and the superior and inferior nerves bilaterally.

Third, the ICS Impulse System is modular. The modules include video Frenzel, VHIT, positional oculomotor and caloric. This means that you're able to purchase different modules at different times depending on the needs of a clinic making it a customizable, practical and cost-effective addition to your equipment.

The fourth advantage is that specifically with peripheral pathologies, results from VHIT testing can monitor central compensation pre and post vestibular rehabilitation. The results help the audiologists to advocate for vestibular rehabilitation and also suggests when therapy can be terminated. This is the only tool in vestibular assessments that provides this.

The fifth advantage is that the goggle design is sleeker, lightweight and comfortable for the patient when doing oculomotor assessments. The goggles are also unlikely to move while moving the patient's head or moving their position. This is a great advantage over the VNG system whose goggles are heavier and more likely to move during testing, making it difficult to observe the pupil well. For example, the impulse goggles are far more comfortable and easier to conduct the Dix Hallpike maneuver with.

Lastly, one great feature on the ICS Impulse System that the VNG does not have is the ability for the recording of the eye to be played back in slow motion. This makes it much easier for the clinician to identify strange eye movements and identify the fast phase of the nystagmus beats.

20. What are the disadvantages of using the ICS impulse compared to the ICS ChartR VNG?

So, while we believe that the ICS impulse system is a fantastic tool, as with everything there are some disadvantages that clinicians need to be aware of if they are using the ICS Impulse System to assess both peripheral and central vestibular pathologies.

The ICS impulse needed to be lightweight as to prevent goggle slippage from the head during impulse testing, the ICS impulse only has one camera which only records eye movements of the right eye. This is for the most part, not a problem because most pathologies affect the movement of both eyes symmetrically. So, recording from just one is sufficient. On the other hand, clinicians may miss pathologies that result in abnormal movement of the left eye.

An example of this would be INO where only the lateral gaze of the affected eye may be impaired. This is often caused as a result of pathology at the level of the medial longitudinal fasciculus commonly caused by strokes or multiple sclerosis.

Although this is said to be a disadvantage, if we think about it, even when using the VNG system, no abnormal eye movements such as INO should come as a surprise to the clinician as a general bedside evaluation of the eyes is conducted beforehand. Here disconjugate lateral eye movement would already have been observed. We may need to ask ourselves the value of continuing with doing oculomotor assessments on either the VNG or Impulse System. At the end of the day, the conclusion from our side would be the same. A central pathology would be suggested, and we would need to refer that patient to a neurologist for further assessment.

Another disadvantage would be that because the camera is on the right if a patient has any eye abnormalities on this side, the test cannot be completed on the patient. For example, if the patient has a droopy eyelid on the right, or if the patient is blind in his/her right eye, or if the crosshair just cannot stabilize for some reason (sometimes all the white eyeliner, white mascara and tape in the world can't stabilize that crosshair). Whereas if you had a problem like this and you were using the VNG system, you would change your settings and only record results from the left eye for your results analysis. If you are using the Impulse System, you may not be able to complete the test and would have to rely on other assessments to make your conclusions and recommendations.

Normative data for the VVOR and VORS test has not yet been established. This means that your results are not summarized and compared to normative data. Results, therefore, need to be analyzed subjectively by looking at the tracings. This means that you need more experience in the interpretation of results.

Another disadvantage of the ICS impulse is that the head movements are controlled by the tester. For those of you who are familiar with the VNG system to assess tracking, the light moves on the light bar between 0.2 and 0.7 hertz, giving you a range of tracking abilities across different tracking speeds. As we've discussed earlier, the tracking pathway is assessed using the VORS assessment in the ICS impulse, and unlike the VNG system, it requires the clinician to move the patient's head from left to right. This means that results could vary between clinician testing as one clinician may have moved the head at 0.2 hertz while testing in the other at 0.5 hertz while testing. An abnormality may be seen at 0.5 hertz but not at 0.2 hertz. One also has to be careful that you are not going over 0.5 hertz as this could result in the peripheral system dominating the response obtained and becoming less sensitive to central pathologies. This problem, however, is easily overcome with the use of a metronome to guide the clinician's speed. This is available as an app and it can be downloaded for free.

As discussed earlier although minimally stimulated, an abnormal vestibular ocular reflex as a result of a peripheral vestibular pathology, can act as a confounding variable and cause abnormalities in your VVOR and VORS assessments depending on how severe or acute the pathology is. This was seen in Ramos and colleague's research conducted in 2018. His research was entitled, "VVOR and VORS testing" as a tool in the diagnosis of unilateral "and bilateral vestibular hyperfunction" should you wish to read a little bit further.

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Citation

Naude, A. & van Rie, K. (2020). Q&A: Utilization of the ICS Impulse vs ICS ChartR VNG for oculomotor assessment with alida naude. *AudiologyOnline,* Article 26638. Retrieved from http://www.audiologyonline.com