The vestibular test battery involves the assessment of the vestibulo-ocular system (Farkashidy, 1966). Routine vestibular assessment involves the recording and analysing of the patient’s eye movement and any type of nystagmus (Bhansali & Honrubi, 1999). Nystagmus can indicate a static imbalance between the resting outputs of the two vestibular systems (Jacobson & Shepard, 2008), and is comprised of a slow and fast phase. The direction of the nystagmus is identified by the direction of the fast phase. The intensity of the nystagmus is defined by the slow-phase velocity. Therefore it is preferable to record the eye movements rather than observation alone to enable quantification to the direction, speed, and amplitude of the nystagmus and to enable comparison between different eye recordings. The recording of nystagmic responses using electronystagmography (ENG) or videonystagmography (VNG) is a widely recognized method for investigating vestibular disorders (Des Couris et al, 2008).

Traditionally, ENG utilized the corneo-retinal potential (CRP) to infer eye position and movements. ENG applies the CRP variation principle during changes in eye position to assess the function of the vestibulo-ocular reflex (Bhansali & Honrubia, 1999) and involves recording voltage changes detected by the electrodes placed around the eye resulting from a known eye movement and comparing the voltages to those of known eye movements. Literature has documented that there can be large variations in the CRP during short periods of time (Proctor et al, 1980; Hickson, 1983). The CRP is affected by a change in pupil diameter and depolarization of the retina when exposed to light. Any lighting variations that may occur during ENG testing can result in a change of calibration due to changes in the CRP. Therefore, frequent recalibration of ENG systems is necessary to reduce calibration errors (Lightfoot, 2004).

VNG uses a computerized system that does not require the placement of electrodes to record eye movements. VNG employs an algorithm to accurately measure any ocular movements from the centre of the pupil (Eggett, 2007) using infrared sensors built in to a set of goggles or mask which are placed over the patient’s eyes. The algorithm enables a two-dimensional analysis of the eye movement; vertical and horizontal. VNG can assess eye deviations from a central position to 30° horizontally and 20° vertically (Gananca...
et al, 2010). During VNG testing, it is also possible to visualize the eye movements which is advantageous to identify any eye movements that cannot be recorded, such as torsional nystagmus (Ruckenstein & Shepard, 2000). VNG has become the preferred method of assessing changes in eye position or movement due to increased sensitivity (Jacobson & Shepard, 2008), an improvement in resolution for recording eye movements in the vertical plane (Eckert & Gizzi, 1998) and increased stability of calibration (Lightfoot, 2004). Unlike ENG, VNG testing can be conducted under any lighting conditions without affecting the accuracy of the calibration. Some VNG systems can offer binocular recording (records movement from both eyes individually) which enable the recording of disconjugate eye movements (Gananca et al, 2010).

VNG calibration is conducted prior to ocular motor assessments and requires the patient to follow a computer-generated moving visual target. Calibration is the process of calculating a conversion factor so that the parameters measured by the recording device can be converted into measurement of the eye movements (Kang & Malpeli, 2003). The type of calibration test can vary between manufacturers, some will require the patient to use fast eye movements to look between fixed points (saccade test) and other systems will require the patient to track a moving target (smooth pursuit) (Barin, 2006). VNG calibration systems also offer a default calibration mode which does not require the patient to follow a moving target. It is always recommended to follow the manufacturer’s specification for calibration testing. An error or faulty calibration recording will result in inaccuracy of the amplitude of eye movements and this may impact upon the data obtained during further subtests of the ENG/VNG test battery (Barin, 2006).

It is stated in the British Society of Audiology (BSA) recommended procedure for caloric irrigation (2010) that ENG/VNG calibration should be conducted prior to testing and recalibrated if the goggles are removed or repositioned, or if the infrared camera within the goggles are repositioned with the goggles in their original placement. This is further supported by Barin (2006) who states recalibration if required if the VNG goggles are moved with respect to the patient’s eyes. However, recalibration may not be always clinically viable due to changes in test position (for example, caloric irrigation) and clinical time restraints of appointment length.

Andrew and Meredith (2009) conducted research into the verification of horizontal VNG calibration using the ChartR equipment and investigated the effect of removing and repositioning goggles on calibration traces on ten participants with no history of peripheral vestibular disorder. The ChartR equipment’s default calibration was also examined to determine whether the default calibration setting was accurate for clinical use and found default calibration overestimated eye deviations. The findings from the study suggest that removing or repositioning the goggles had no significant clinical effect on the initial horizontal calibration, indicating that recalibration is not necessary if the goggles were to be removed and repositioned.

However, the findings from Andrew and Meredith’s (2009) work cannot be applied to other VNG systems due to differences in calibration systems and VNG goggle design. At Wrexham Maelor Hospital, Wales, the current VNG system is the Synapsys VNG Ulmer. The Synapsys VNG Ulmer system differs from the ChartR system as it uses a saccade calibration test instead of smooth pursuit and has VNG goggles with a detachable infrared camera (Figure 1, a–c) as opposed to the ChartR VNG goggles which has an inbuilt infrared camera. Also, the Synapsys VNG Ulmer uses a different default calibration test to the ChartR system.

The default calibration setting on the Synapsys VNG Ulmer system is also known as geometric calibration and will be referred to as geometric calibration in this paper. The geometric calibration consists of measuring the patient’s iris diameter as one of the parameters of the ocular image. This is conducted by measuring the horizontal width of the patient’s iris on the VNG software (Figure 2). The measurement of the patient’s iris is compared to manufacturer gathered data and this enables the eye deviation to be calculated from any movement from the centre of the pupil. As the geometric calibration is based upon approximations of the actual diameter of the patient’s iris it is less accurate, therefore the Synapsys VNG Ulmer manufacturers advise that geometric calibration should only be activated if a patient is unable to conduct a visual calibration (VNG Ulmer User Manual, version C4-12C).

Due to the differences between the ChartR and Synapsys VNG Ulmer systems, the aim of this study was to develop the past work by Andrew and Meredith (2009) using the Synapsys VNG Ulmer equipment at the Wrexham Maelor Hospital, Wales. The study aim was to assess the accuracy and stability of the patient conducted

**Figure 1.** The VNG goggles used for the recording of eye deviation. (a) The VNG mask. (b) VNG camera in situ monitoring the left eye with the right eye uncovered (recording condition). (c) Light-excluding cover in situ over right eye. (d) Side profile of VNG camera illustrating range of camera movement.
This system uses a monocular recording of eye movements. The VNG goggles consist of a mask (Figure 1, a) with a detachable camera (records eye movements) which is placed over one eye (Figure 1, b), and a detachable light-excluding cover to remove fixation (Figure 1, c). Once the camera is in position, it provides a completely dark environment for the test eye (eye monitored by infrared camera). As the camera is detachable, the test eye is usually selected to be the eye with the poorer vision to ensure the patient can clearly visualize the light target with the non-test eye.

The Synapsys VNG Ulmer system calibration test is a saccade test over an eye deviation of ±10°. The equipment offers both horizontal and vertical calibration tests. However, at Wrexham Maelor Hospital routine clinical assessment usually involves horizontal calibration only. This is as all horizontal nystagmus is measured to determine the significance of the nystagmus (nystagmus ±3° is reported as significant) whereas the recording of any vertical nystagmus is reported as significant.

**Experiment 1: Assessment of calibration accuracy**

**Baseline calibration assessment**

Each participant underwent the system’s recommended calibration test using horizontal saccade testing. The participant was seated in a central position at a fixed distance from the projector screen (2.19 m) with the light target at eye level. Each participant was instructed to follow the light target on the projector screen with their eyes without making head movements. During recordings, the test eye was alternated between participants (11 right test eyes and 11 left test eyes) to eliminate any potential test eye bias.

After the horizontal calibration test had been completed, the horizontal calibration waveform was visually inspected by either author to ensure no abnormalities, such as poor accuracy, latency, or velocity were present before testing continued. Horizontal gaze testing was then performed to record the actual eye deviation at a known angle of 60°. The horizontal gaze test involved the participant looking with their eyes +30° (right) to −30° (left) while maintaining their head in a central position. These eye deviations were selected as it is routine clinical practice to measure eye movements at ±30° during gaze testing. If the angle was too large in gaze testing, end point nystagmus may be produced and errors seen in normal participants, however a sufficient angle is required during gaze testing to provide an effect in pathological cases. The recorded eye movements from looking +30° (right) to −30° (left) provided the baseline measurements. Three non-randomized conditions were conducted and analysed to assess their effect on the baseline calibration results. To eliminate any bias from the previous condition, horizontal calibration was repeated after each condition to ensure that an accurate comparison between the condition and the baseline measurement was achieved.

**Condition 1: Goggles removed and repositioned**

After conducting the baseline measurements (as described above), the goggles were removed while preserving the angle of the infrared camera and the participant was asked to walk around the test room. The participant was then asked to return to their initial seated position and the goggles were again placed over the participant’s eye. As this study wanted to investigate the effect of removing and replacing the goggles within a clinical setting, no formal assessment was conducted to ensure the participant had returned to their exact, initial seated position. Horizontal gaze testing was repeated
to compare the eye deviations and examine the effect of removing and repositioning the goggles.

**CONDITION 2: INFRARED CAMERA REPOSITIONED WITHIN THE GOGGLES**

The angle of the infrared camera can be adjusted to ensure a clear recording of the test eye. The infrared camera angle can be rotated 360° on the horizontal axis and can be moved approximately 45° on the vertical (Figure 1, d).

During this condition, the angle of the infrared camera within the goggles was adjusted from the initial calibration test. The camera was rotated approximately 180° horizontally and moved approximately 45° vertically. After the infrared camera had been adjusted, the camera was repositioned to maintaining a suitable recording of the test eye. Horizontal gaze testing was repeated to compare the eye deviations and examine the effect of repositioning the infrared camera within the goggles after conducting calibration.

**CONDITION 3: INFRARED CAMERA AND GOGGLES REMOVED AND REPOSITIONED**

Condition 3 is a combination of the elements in conditions 1 and 2. Following the baseline measurements of eye movement was made, the patient was asked to walk around the room. Once the participant returned to a central, fixed seated position the goggles were replaced to the same position while the angle of the infrared camera had been adjusted. Horizontal gaze testing was then repeated to compare the eye deviations to the baseline measurement.

**Experiment 2: Assessment of the geometric calibration**

In accordance to the manufacturer’s recommendation (VNG Ulmer User Manual, version C4-12C), the assessment of geometric calibration was conducted by measuring the horizontal width of the participant’s iris. This was performed by the application of cursors to the outer boundary of the iris on a captured static image of the participant’s eye (Figure 2). This enables the equipment to estimate the eye deviations by comparing the movement of the pupil in comparison to manufacturer stored normative data. Horizontal gaze testing was then performed to record the actual eye deviations of a known angle of 60°. The obtained results were compared to the baseline results obtained in experiment 1.

**Statistical analysis**

The actual eye deviation results for each condition were compared to the baseline eye deviation results (calculated before each condition) using one tailed paired sample T test. For experiments 1 and 2, a Bonferroni correction was applied, so that for experiment 1, test conditions 1 to 3, the p value used was p < 0.0167 and for experiment 2, p < 0.025 was used.

**Results**

**Experiment 1: The effect of goggle and infrared camera movement on initial calibration testing**

The mean eye deviation from the baseline measurement was 56.4° (± 1.4°). The individual results from the baseline measurement were compared with the findings from each condition.

**CONDITION 1: GOGGLES REMOVED AND REPOSITIONED**

Figure 3 displays the individually gathered data obtained from condition 1 (grey coloured bar) in comparison to the baseline measurements (white coloured bar). The last bar (titled ‘mean’) shows the data averaged for all 22 participants from condition 1 and the baseline measurements. The error bars represent the standard deviation. The mean (standard deviation) eye deviation for condition 1 was 55.1° (5.2). There was no significant difference found between the baseline

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**Figure 3.** Individual and average baseline calibration results compared to recordings after the goggles had been removed and repositioned. The error bars represent the standard deviation of the mean values.
eye deviation testing results and the eye deviation results recorded after the goggles had been removed and repositioned (p = 0.21). This suggests that moving the goggles does not have a significant effect on the initial calibration. However, there is a relatively large standard deviation of 5.2° (9.4%) for condition 1 in comparison to the baseline measurement standard deviation of 1.4° (2.5%). This indicates that there is a greater variation in eye deviation measurements once the goggles are repositioned.

**Figure 4.** Individual and average baseline calibration results compared to recordings after the infrared camera within the goggles had been repositioned. The error bars represent the standard deviation of the mean values.

**Condition 2: Infrared camera repositioned within goggles**

Figure 4 shows the results obtained from condition 2 in comparison to the baseline measurements. The mean bar on Figure 4 shows the eye deviation for condition 2 was 56.6° (1.9). There was no significant difference found between the baseline eye deviation testing results and the eye deviation results recorded after the infrared camera angle within the goggles had been repositioned (p = 0.50). This finding suggests that repositioning the infrared camera angle

**Figure 5.** Individual and average baseline calibration results compared to recordings after the goggles and infrared camera within the goggles had been repositioned and replaced. The error bars represent the standard deviation of the mean values.
Verification of Synapsys VNG Calibration System
during testing does not have a significant effect on the initial
calibration. The standard deviation for condition 2 of 1.9° (3.4%)
is similar to the standard deviation from the baseline condition 1.4°
(2.5%) indicating that there is not a greater variation in eye deviation
measurements once the infrared camera had been repositioned.

**CONDITION 3: INFRARED CAMERA AND GOGGLES REPOSITIONED**
The individual results obtained from condition 3 are shown in
Figure 5 in comparison to the results from the baseline measure-
ment. For condition 3, the mean eye deviation was 55.6° (3.2).
No significant difference was found between the baseline eye deviation
testing results and the eye deviation results recorded after the
goggles and infrared camera within the goggles had been removed
and the infrared camera angle repositioned (p = 0.18). This suggests
that moving the goggles and infrared camera does not have a signif-
cicant effect on the initial calibration. The standard deviation for
condition 3 is displayed as an error bar on Figure 5. The standard
deviation for condition 3 of 3.2° (5.8%) is greater than the baseline
measurement standard deviation of 1.4° (2.5%). This indicates that
there is a greater variation in eye deviation measurements once the
goggles and infrared camera have been repositioned.

**Experiment 2: The accuracy of geometric calibration**
Figure 6 displays the eye deviation results obtained from all 22
participants after the geometric calibration had been activated. These
results were compared to the results obtained from the baseline mea-
surement condition in experiment 1. The error bars represent the
standard deviation. The mean eye deviation for experiment 2 was
49.2° (3.3). A significant difference was found between the obtained
baseline recordings from experiment 1, t(21) = 9.755, p < 0.01
with the recordings obtained after geometric calibration was applied.
As shown in Figure 6, the geometric calibration was found to
underestimate the true eye movement for each participant except
for one participant (participant ID 3). Therefore, the geometric cali-
bration underestimated the eye deviations in 95% of participants
and by an overall mean of 7.2° (13%). The standard deviation for
experiment 2 is 3.3° (6.7%) which is greater than the baseline mea-
surement standard deviation of 1.4° (2.5%). This indicates that there
is a greater variation in eye deviation measurements when activating
the geometric calibration than conducting visual calibration. How-
ever, it should be noted that the baseline recordings were lower than
the expected eye deviation of 60° and this may contribute towards
the significant difference between the baseline recordings and the
eye deviation measurements made after the geometric calibration
was activated.

**Discussion**
The results from experiment 1 showed that removing and reposi-
tioning the goggles (condition 1), repositioning the infrared camera
angle (condition 2), or repositioning both the infrared camera and
goggles (condition 3) did not have any significant effect on the initial
visual calibration results. The finding from condition 1 is consist-
ent with the finding reported by Andrew and Meredith (2009) that
removing and replacing the VNG goggles did not affect initial cali-
bration on the ChartR system. The study by Andrew and Meredith
(2009) did not examine the effect of adjusting the camera angle on
calibration. The findings from this study suggest that recalibration
may not be necessary when the goggles and/or infrared camera have
been repositioned.

The main parameter that influences VNG calibration is the dis-
tance of the camera from the participant’s eye. VNG goggles are
designed to keep the distance between the camera and eye constant.
Therefore, a possible explanation to why the initial calibration was
maintained despite moving or repositioning the goggles and/or infra-
red camera is due to the camera to eye distance remaining constant.
This results in the initial calibration being maintained. The findings
reported from this study differ to those recommended by the BSA
(2010) caloric irrigation recommended procedure who state that the
VNG system should be recalibrated if the goggles and/or camera are
repositioned during testing. However, the BSA (2010) recommended

![Figure 6. Individual and average eye deviation results after geometric calibration in comparison with the baseline measurement. The error bars represent the standard deviation of the mean values.](image-url)
procedures do not provide any reasoning to justify why recalibration is required if the goggles/infrared camera were to be repositioned during testing. Barin (2006) reports that recalibration is required only when the goggles or the camera are moved in respect to the patient’s eyes due to a change in the camera to eye distance. Therefore, as camera to eye distance will not change significantly to have an effect the initial calibration due to the design of the VNG goggles, the findings from the study support that repositioning the goggles and/or camera during testing does not require recalibration.

The comparison between the eye deviation results obtained from performing geometric calibration (Experiment 2) and the baseline measurements obtained by conducting the system’s horizontal saccade test (to record the actual eye deviations of a known angle of 60°) revealed a significant difference (p < 0.01). This is supported by Andrew and Meredith (2009) who concluded in their study using the ChartR VNG system that the default calibration did not provide a good approximation of the true eye deviation. During the geometric calibration, the true eye deviation is estimated by measuring the iris width in comparison to manufacturer data to calculate the degree of eye movement from the centre of the pupil. This method of calibration will have limited accuracy as it is dependent on the precision of measuring the iris width and the comparison to the manufacturer’s normative data. This study found that the geometric calibration of the Synapsys VNG Ulmer system underestimated the true eye deviation by a mean of 13% (7.2°). This may have implications during clinical testing as it will increase the likelihood of not detecting a significant nystagmus because the slow-phase velocity will be underestimated. This may affect diagnosis of nystagmus due to peripheral or central causes in gaze testing, positional testing, and caloric testing. An example of when this may affect patient diagnosis is bilateral or central causes in gaze testing, positional testing, and caloric testing. Based upon these results, recalibration may not be required if the VNG goggles and/or infrared camera are removed or repositioned during testing. However, due to the individual variability noted in the results, it may be advisable to adhere to the recommendations stated by the BSA (2010) recommended procedures regarding recalibration during VNG testing.

Caution needs to be exercised when using the geometric calibration within the Synapsys VNG Ulmer equipment and should be used only if the patient is unable to perform the system’s recommended saccade calibration test.

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