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Comparison of two systems for the video head impulse test (vHIT) for the lateral semicircular canal: description of results from normal and pathological subjects

Comparação de dois equipamentos para realização do teste de impulso cefálico por vídeo (vHIT): resultados em indivíduos normais e patológicos

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ABSTRACT

Background: The video head impulse test (vHIT) is a recent technique for functional evaluation of semicircular canals (SSCs). The vHIT examines eye movements at high frequencies of stimulation and provides an objective assessment of the functioning of the high-frequency domain of the vestibular system. **Objective:** To describe the results from vHIT performed using two systems. **Methods:** All subjects were evaluated through an audiological and otoneurological battery of tests and were diagnosed as normal or abnormal by an otorhinolaryngologist. The results from two systems: 1. ICS Impulse (Otometrics/Natus, Denmark) and 2. EyeSeeCam (InterAcoustics, Denmark) were recorded. The same operator delivered every impulse to every subject. The head impulses were performed while the operator was standing behind the subject, using both hands on the top of the subject's head, well away from the goggles strap and forehead skin. Two calibrations were completed in each system, prior to beginning the test. **Results:** Test parameters were recorded through both systems for healthy subjects with no history or complaint of any vestibular disorder (N = 12; M/F = 5/7; age 35.1 ± 13.5 y) and for pathological subjects with a diagnosis of unilateral or bilateral vestibular disorder (N = 15; M/F = 7/8; age 53.4 ± 16.7 y). **Conclusions:** The vHIT is an important tool for otoneurological complementary evaluation. Both systems are reliable for vestibular disorders. The EyeSeeCam seems to reject fewer data and provides more information to include in diagnostics. Because of the small sample, there is a need for further in-depth comparison of both systems.

Keywords: Diagnosis; Head Impulse Test; Postural Balance; Semicircular Canals; Vestibular Function Tests.

RESUMO

Introdução: O Teste de Impulso Cefálico por Vídeo (vHIT) é uma técnica empregada para avaliação funcional dos canais semicirculares (CSCs). O vHIT examina o movimento dos olhos relativo ao movimento cefálico em altas frequências e oferece uma avaliação objetiva da função do sistema vestibular. **Objetivo:** descrever os resultados do vHIT utilizando dois equipamentos distintos. **Métodos:** Todos os indivíduos foram avaliados por meio de uma bateria de exames audiológicos e otoneurológicos e diagnosticados como sem alteração ou com distúrbio vestibular por um médico otorrinolaringologista. Os resultados dos dois sistemas: 1. ICS Impulse (Otometrics/Natus, Dinamarca) e 2. EyeSeeCam (InterAcoustics, Dinamarca) foram registrados. O mesmo operador realizou todas as estimulações. O examinador se manteve atrás do indivíduo, com as duas mãos sobre o topo da cabeça do mesmo de forma a não tocar na máscara nem no elástico da mesma durante todo o registro. Antes de iniciar o teste, duas calibrações foram realizadas em cada sistema. **Resultados:** Indivíduos saudáveis sem história ou queixa de qualquer distúrbio vestibular (N = 12, M/F = 5/7, idade 35,1 ± 13,5 anos) e indivíduos com diagnóstico confirmado de distúrbio vestibular unilateral ou bilateral (N = 15, M/F = 7/8, idade 53,4 ± 16,7 anos) tiveram parâmetros de teste descritos em cada sistema. **Conclusões:** O vHIT é uma importante ferramenta para avaliação otoneurológica complementar. Ambos os equipamentos são confiáveis para avaliação dos distúrbios vestibulares. Em nossa opinião, o EyeSeeCam parece rejeitar menos dados e fornece mais informações para incluir no diagnóstico. Devido à pequena amostra, torna necessário uma comparação mais aprofundada de ambos os sistemas.

Palavras-chave: Diagnóstico; Teste de Impulso Cefálico; Equilíbrio Postural; Canais Semicirculares; Testes de Função Vestibular.

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INTRODUCTION

The vestibular system is mainly engaged in three bodily functions: image stabilization, postural control and space orientation. Unilateral or bilateral malfunctioning of the peripheral portion of this system can seriously affect the ability to maintain balance, walk and maintain visual acuity and gives rise to an overall reduction in quality of life[1].

Proper integration of diagnostic tools during examination is a requirement for good clinical practice, in order to pinpoint the cause and location (central/peripheral) of the vestibular deficit[2]. These tools include, but are not limited to, a caloric test, head impulse test (HIT), oculomotor investigation, use of a rotating/translating chair, vestibular evoked myogenic potential (VEMP) and posturography[3].

The head impulse test (HIT) can be used complementarily to caloric testing. It is useful for bedside examination of the semicircular canals since it provides information regarding higher frequency sensitivity of the vestibular-ocular reflex (VOR): < 0.002 Hz for caloric testing[4] and up to 0.8 Hz for HIT.

As with many otoneurological diagnostic tools, the HIT stimulates the VOR to assess semicircular canal function. Under normal circumstances, the VOR ensures visual acuity through image stabilization when the head is moving in a translational and angular fashion[5].

In healthy subjects, the latency of this reflex is ~10 ms, which is the time required for the eyes to respond at a similar speed, but in the opposite direction to the motion of the head[5,6].

During rotational head movement, the endolymphatic fluid within the semicircular canals deflects the cupula in the opposite direction due to inertia. Endolymphatic flow towards the ampulla is excitatory in the horizontal canals and inhibitory in the vertical canals, and vice versa. The VOR can be depicted simplistically as a three-neuron arc involving the afferent nerves from the ampulla, the major vestibular nuclei (medial vestibular nucleus, lateral vestibular nucleus, inferior vestibular nucleus and superior vestibular nucleus) and the oculomotor nuclei that drive eye muscle activity[1].

However, the HIT relies strongly on the observer's detection capabilities and, hence, interobserver variability can be expected to be high. Correctional saccades after application of the head impulse, named overt saccades, can be observed by the trained eye. However, correctional saccades that occur during the head impulse, named covert saccades, are more difficult, if not impossible, to observe with the naked eye[5-7].

High-speed pupil tracking using video recording enables documentation of subtle changes in eye movement non-invasively during and after a head impulse. This method is referred to as vHIT (video head impulse test) and it has been shown that results from using this technique correlate highly with the gold standard, which is called the scleral search coil technique[4-8].

Moreover, eye movement can be correlated with unpredictable abrupt head movement through incorporating a high-speed video camera for detecting eye movement and accelerometers for three-dimensional head movement, in tightly fitting goggles. This enables determination of eye position and speed relative to head position and speed per enforced head impulse. Head rotations are typically applied at a 10-20° angle at speeds of 100°/s to 300°/s[7,8].

Based on the utility of vHIT, the objective of this study was to describe the results from vHIT in normal and pathological subjects using two different systems.

METHODS

The study protocol was approved by the institutional ethics review board and was implemented in accordance with the ethics code of the World Medical Association (Declaration of Helsinki). All subjects provided written informed consent prior to their participate in the study.

Subjects

All subjects were evaluated through a complete audiological and otoneurological battery of tests, e.g. audiometry, tympanometry and auditory brainstem response (ABR), along with balance tests, Dix-Hallpike test, head roll test, oculomotor evaluation, caloric test with water stimuli, rotatory chair tests, posturography, ocular and cervical vestibular evoked myogenic potentials (VEMPs), and vHIT). Through these, all the subjects were evaluated and diagnosed as normal or abnormal, by an otorhinolaryngologist.

Healthy subjects without balance disorders (N = 12; M/F = 5/7; age 35.1 ± 13.5 y) took part as controls. To be included in the study group, subjects needed to present a unilateral or bilateral vestibular disorder (N = 15; M/F = 7/8; age 53.4 ± 16.7 y).

All the participants were informed about the results from the vHIT for experimental and complementary diagnostic purposes. Each evaluation was performed by the same examinator using two systems: 1. ICS Impulse (Otometrics/Natus, Denmark); and 2. EyeSeeCam (InterAcoustics, Denmark).

For both examinations, two calibrations were completed in each system, prior to beginning the test. The subject was instructed to maintain a fixed gazer on an earth-fixed target, which was usually straight ahead, while the operator delivered brief, passive head turns, which were unpredictable in size, direction, velocity and timing. Each subject was seated in a height-adjustable, rotatable office chair, so that their head was located at the ideal height for the operator to deliver horizontal impulses. The head velocity signal used in the processing was a component of the three-dimensional head velocity, as measured by the sensor set in the plane of the test. For example, in the left anterior and right posterior (LARP) plane, the head velocity signal was the one measured by the sensor in the LARP orientation. The horizontal vHIT stimulus consisted of a small, passive, abrupt horizontal head rotation, which the operator delivered in an unpredictable direction, at an unpredictable magnitude, and with minimal "bounce-back" at the end of the head impulse: each impulse was a short sharp "turn and stop". All tests were performed by the same right-handed operator. The impulses were performed by the operator while standing behind the subject, using both hands on the top of the head, well away from the goggles strap and forehead skin[5-9].

Hardware

The EyeSeeCam was coupled via firewire to an Apple MacBook Pro and was controlled via the EyeSeeCam software (revision r3373). The ICS Impulse was coupled via USB 2.0 to a Samsung NP900X3E notebook running the OTOsuite Vestibular Software V2.00 Build 605.

Data processing

The ICS Impulse (Impulse 3.0 reference manual, version 2015) determines the peak speed of the head and eye per impulse and calculates the gain as (peak $\text{speed}_{\text{eye}}$/peak $\text{speed}_{\text{head}}$). However, both the head movement and the eye movement must meet predefined criteria before the gain can be calculated; if one (or both) of the criteria is not met, the measurement is rejected. These gains are depicted in a graph, with the gain on the y-axis and peak head speed on the x-axis.

The average gain ± standard deviation is expressed numerically for head rotations to left and right. Gains < 0.8 are considered pathological. ICS calculates VOR gain as the ratio of the area under the eye velocity and head velocity curve (from 60 ms before peak head acceleration to the last value of 0°/s as the head returns to rest). (ICS Impulse manual, version 2013).

The EyeSeeCam calculates the gain in a continuous fashion until reaching 150 ms after the start of the head impulse, by dividing the eye speed by the head speed at various time points. The median of the gain is determined at 40, 60 and 80 ms after the impulse and the gain is expressed at these time points as the median ± SD.

The median is chosen over the average in order to reduce the influence of outliers. A plot of gain versus maximum head speed is presented per impulse, in which the gain is calculated by determining the gradient of the linear regression between the head and eye velocities (EyeSeeCam manual, version 2007).

RESULTS

The results were described according to the group (control or study) and the diagnosis after the physician's clinical evaluation.

Healthy subjects

Healthy subjects showed gains ranging from 0.85 to 0.95 for the ICS Impulse, whereas for the EyeSeeCam the gains ranged from 0.99 to 1.25 (gains > 1.5 could not be taken into account in this analysis, meaning that the true upper limit was higher). Looking at each healthy subject individually, the EyeSeeCam provided gains that were systematically higher than those from the ICS Impulse, even including values > 1, which were physiologically impossible. This implies that the absolute gain values obtained with the EyeSeeCam should be interpreted with caution until the underlying cause of this observation has been identified.

Figure 1 shows the responses from two healthy subjects, measured using the EyeSeeCam and ICS Impulse, respectively. The second healthy subject (D) displayed traces that were morphologically highly deviant from (B) using the same equipment (ICS Impulse). These could be labeled as pathological when looking solely at the vHIT as a diagnostic tool. Moreover, several gains were > 1.5, partially caused by the fact that eye velocity traces preceded head velocity traces.

Subjects with vestibular disorder

1. Unilateral areflexia

The EyeSeeCam showed both strong overt and strong covert saccades; the ICS Impulse showed mainly overt saccades (Figure 2 – A and B). Interestingly, the overall gains for the EyeSeeCam were approximately 0.9 and 1.1 for right and left-side impulses respectively, leading to an asymmetry of 18%, to the disadvantage of the right side, whereas for the ICS Impulse these were approximately 0.7 and 0.5, with 26% asymmetry to the disadvantage of the left side. Thus, the overall gain results from the EyeSeeCam were in line with the caloric test, whereas the ICS Impulse showed opposite results.

2. Bilateral areflexia

Through applying the EyeSeeCam for vHIT (Figure 2 – C), strong covert saccades were observed for both sides. For right-side impulses, the eye velocity traces were readily reproducible, whereas for left-side impulses the covert saccades appeared more randomly distributed. Although these results qualitatively matched the caloric findings, the average gains for the right and left-side impulses were 0.75 and 0.8, respectively. This example illustrates that the absolute gains of the EyeSeeCam were not fully reliable, since one would expect lower gain values with bilateral areflexia. For this patient, all VORs measured with the ICS Impulse were rejected.

3. Unilateral hypofunction

The next subject had hypofunction of the right horizontal semicircular canal, with a normally excitable left horizontal canal. The EyeSeeCam showed clear overt and covert

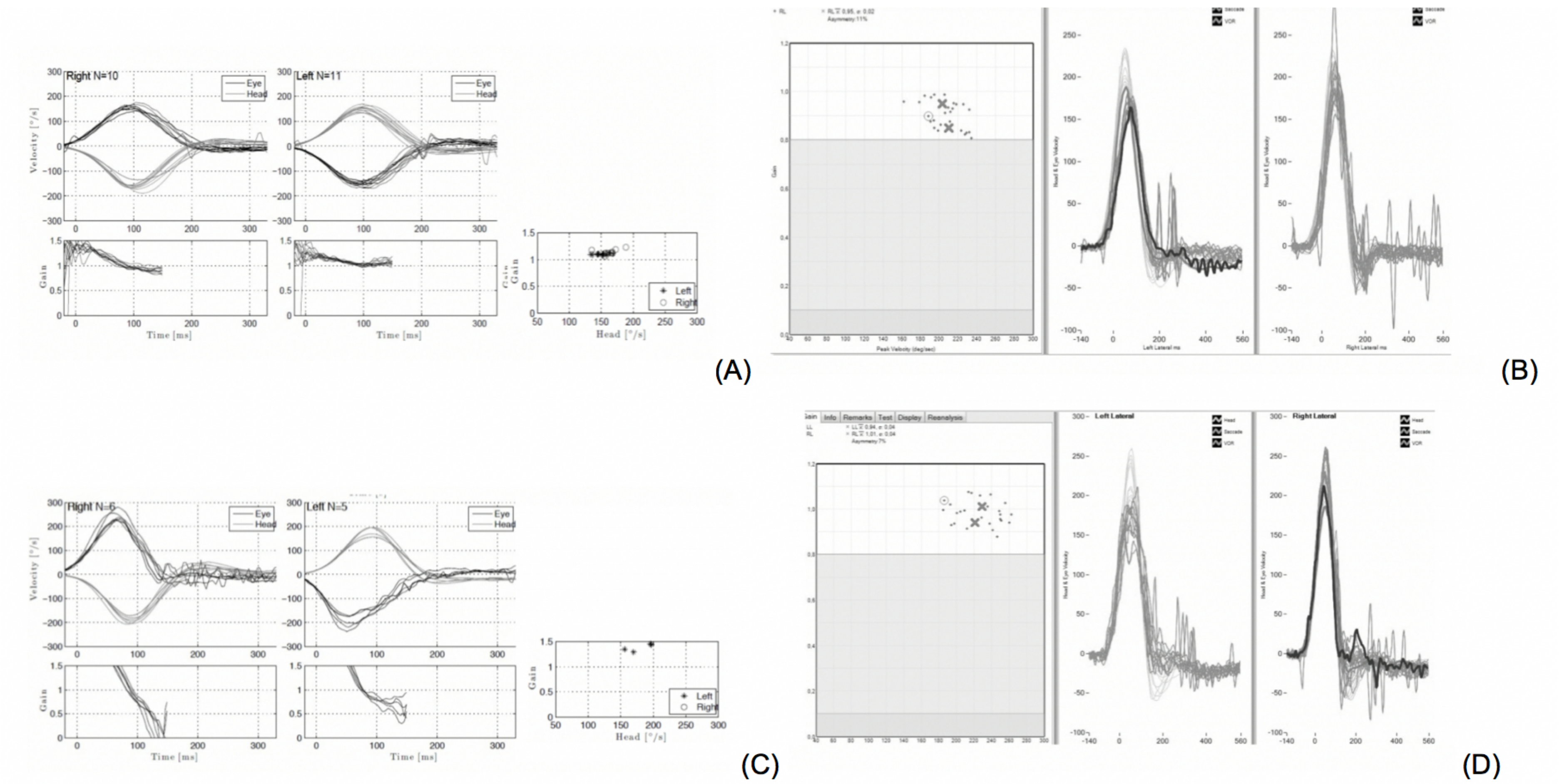

Figure 1. (A) vHIT velocity traces (upper 2 panels) and gains (lower 3 panels) obtained using the EyeSeeCam on a healthy subject. The velocity traces clearly appear to be symmetrical on both sides of the peak velocity. Although the eye velocity traces display minor irregularities post-impulse, these are non-pathological. The gain vs time graphs show a typical decay that was observed in the majority of the healthy subjects. Moreover, no apparent asymmetry can be observed regarding the gains in the lower right panel (gain vs head velocity). (B) The same healthy subject as in (A), measured using the ICS Impulse. Notice that the gains obtained, calculated from peak velocities, are non-pathological, yet display (non-pathological) asymmetry of 11%. Moreover, the VOR (the eye velocity in °/s) displays what appears to be multiple overt saccades for both right and left-side impulses, yet the software does not label them as such. (C) For the second healthy subject, the vHIT velocity traces (upper 2 panels) and gains (lower 3 panels) were obtained with the EyeSeeCam. The head and eye velocity traces appear to be readily symmetrical for right head impulses, whereas for left head impulses the traces of the eye velocity are non-symmetrical. Note the irregularities in the eye velocity traces following right-side head impulses. Moreover, eye peak velocities are higher than head peak velocities, leading to gains > 1, and are reached approximately 15 ms earlier. The gain vs time graphs show very strong decay, which was observed in one additional healthy subject as well; gains are > 1.5 with multiple impulses, but are not displayed in the gain vs. head velocity graph due to axis limitations. (D) Same subject as in (C), measured with the ICS Impulse. Notice that the gains obtained, calculated from peak velocities, are non-pathological, yet display a (non-pathological) asymmetry of 7%. Furthermore, the individual VORs (the eye velocity in °/s) are highly irregular for left-side impulses, whereas for right-side impulses these are smooth. Approximately 7 VORs are labeled as (covert) saccades for right-side impulses, whereas this was not apparent with the EyeSeeCam. USA, 2019.

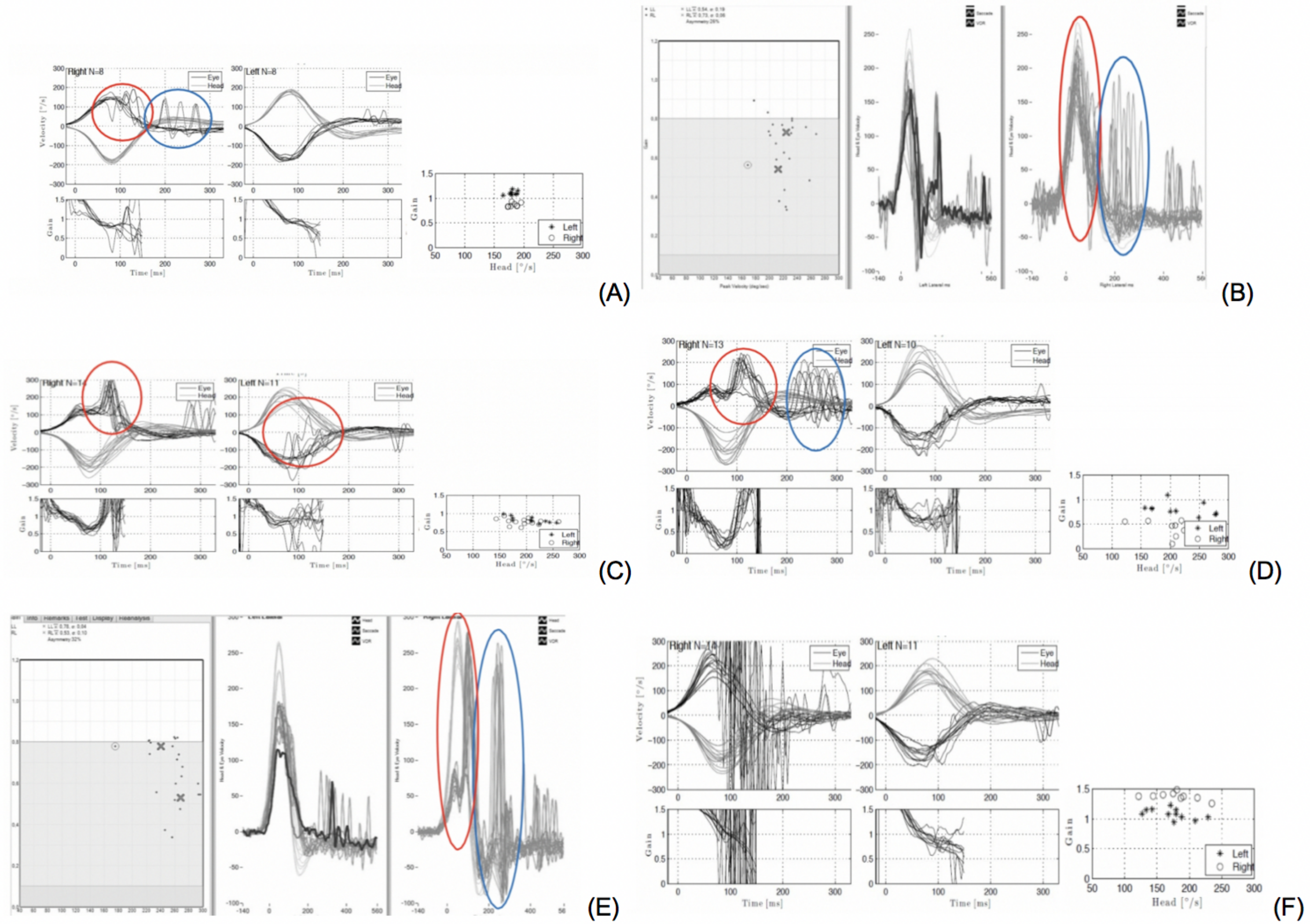

Figure 2. Results from subjects with unilateral or bilateral areflexia or hypofunction. (A) The EyeSeeCam of a patient with unilateral areflexia. The head and eye velocity traces appear to be readily symmetrical for right and left-side impulses. Clear covert (red circle) and overt (blue circle) correctional saccades can be observed with right-side impulses, whereas eye velocity traces for left-side impulses are smooth (upper 2 panels). (B) Clear covert (red circle) and overt (blue circle) correctional saccades can be observed with right-side impulses, whereas eye velocity traces for left-side impulses are smooth. Based on the criterion that gains < 0.8 are pathological, both sides have diminished function. (C) The EyeSeeCam of a patient with bilateral areflexia. Clear covert (red circle) correctional saccades can be observed with both right and left-side impulses (upper 2 panels). (D) The EyeSeeCam results of a patient with unilateral hypofunction. Clear covert (red circle) and overt (blue circle) correctional saccades can be observed with right-side impulses (upper 2 panels). (E) ICS Impulse of the same patient with unilateral hypofunction. Clear covert (blue circle) and minor covert (red circle) correctional saccades can be observed with right-side impulses. (F) The EyeSeeCam results of a patient with bilateral hypofunction. Notice the strong irregularities with right-side impulses. USA, 2019.

correctional saccades for right-side movement, with an average gain of approximately 0.5 (Figure 2 – D). Correctional saccades were absent for left-side impulses with an overall gain of approximately 0.8. This led to calculated asymmetry of 38%, to the disadvantage of the right side. Moreover, the spread in gain for both sides (right 0.2-0.5; left: 0.6-1.1) was relatively large. The VORs for mainly left-side impulses showed minor irregularities. This meant that the velocity traces were not smooth, but the cause of this remains unknown. In this case, the overall gains obtained with the EyeSeeCam closely matched the gains obtained with the ICS Impulse (Figure 2 – E) for both right and left-side impulses; the asymmetry was 32% to the disadvantage of the right side.

4. Bilateral hypofunction

Using the EyeSeeCam, strong irregularities in the eye velocity traces were visible, with right-side impulses in 10 out of 14 impulses. The ICS impulse measurements were all discarded due to excessive blinking, as derived from the recorded video. This might also be the cause of the irregular impulses obtained with the EyeSeeCam.

The asymmetry calculated from the overall gains of the EyeSeeCam was approximately 21%, with overall gains of 1.1 and 1.4 from left and right-side impulses, respectively. Although the absolute gains of the EyeSeeCam were ≥ 1, these results might indicate that there was symmetrical hypofunction with low-frequency stimulation and asymmetry of vestibular function with high-frequency stimulation (Figure 2 – F).

5. Benign paroxysmal positional vertigo (BPPV) – posterior canal

The EyeSeeCam responses showed high average gain values for the right and left sides (1.4 and 1.2) (Figure 3 – A), whereas for the ICS Impulse these values were 1.1 and 0.8, respectively (Figure 3 – B). Thus, with both systems, asymmetry was found, to the disadvantage of the left side (14% for the EyeSeeCam and 25% for the ICS Impulse).

6. Superior semicircular canal dehiscence syndrome (SCDS)

This patient had successful surgery for SCDS (left side) in 2013, yet had developed symptoms that closely matched symptoms noted before surgery. The vHIT using both systems (Figure 3 – C and D) showed relatively smooth symmetrical eye velocity traces with normal gain values, although gain values for the EyeSeeCam were higher (Figure 3 – C). There was no apparent asymmetry.

DISCUSSION

Qualitative comparison showed that the two systems gave similar results, albeit that in one particular case, the results from the ICS Impulse were opposite to those from the EyeSeeCam (in the patient with unilateral areflexia)[10].

However, quantitative comparison showed clear deviations between the two systems, which may have been caused by: (1) the data processing method, since the ICS Impulse uses the ratio of peak velocities of head and eye movements whereas the EyeSeeCam uses linear regression of the complete velocity traces; (2) physical and detection differences between the goggles, for example: goggle weight, sensitivity and temporal resolution of the camera, sensitivity of the accelerometers and accuracy of the pupil tracking software; or (3) no standardization technique was applied to ensure that the two systems were positioned on the subjects' heads with similar tension; therefore, variation in movement of the goggles relative to the head during application of the impulse cannot be fully ruled out[11].

While this study focused on lateral rotation in testing the horizontal canal, the function of both vertical semicircular canals can also be assessed[12]. Nevertheless, initial testing was performed to assess the left anterior and right posterior (LARP) canal, which proved promising.

In order to properly interpret the results from the vHIT, several phenomena need to be taken into account: (1) Are the velocity traces of the head and eye reproducible? (2) Is symmetry present in the head and eye velocity traces? (3) How are the head and eye velocity traces positioned with respect to one another? (4) Are covert and/or overt correctional saccades visible in the eye velocity traces? (5) What is the range of gain values in the gain vs head velocity plot?[11-14].

Several recommendations can be made in order to properly perform the vHIT: (1) The v-HIT goggles should be tightly fitted, preferably with controlled tension; (2) Hands should not directly touch the vHIT goggle or strap while manipulating the head; (3) In order to minimize the effect of the difference in rotation axis between the eyes and head, the minimum distance between the subject and the wall should be 1.5 meters; (4) The computer screen should be facing the observer, not the subject, in order to directly evaluate the VOR after the head impulse; (5) The subject must be given clear instructions to continuously focus on the object of fixation with the eyes wide open and relax the neck as much as possible when the head is returned to the neutral central position; and (6) VORs should be acquired at three ranges of head velocities: 100-150°/s, 150-200°/s and 200-250°/s[5,6, 9,10,13,14].

This study has some limitations. The sample size was considered to be too small to perform statistical analysis, and no discrimination was made between subjects in terms of age and visual impairment. The VOR gain appeared to be largely independent of age[11]. These measurements were performed over a wide range of ages (healthy subjects: 29-52 years; patients: 25-75 years). Moreover, from an analytical point of view, it would be interesting to quantify the area under the curve (AUC), since this value should be equal for the head and eye velocity traces.

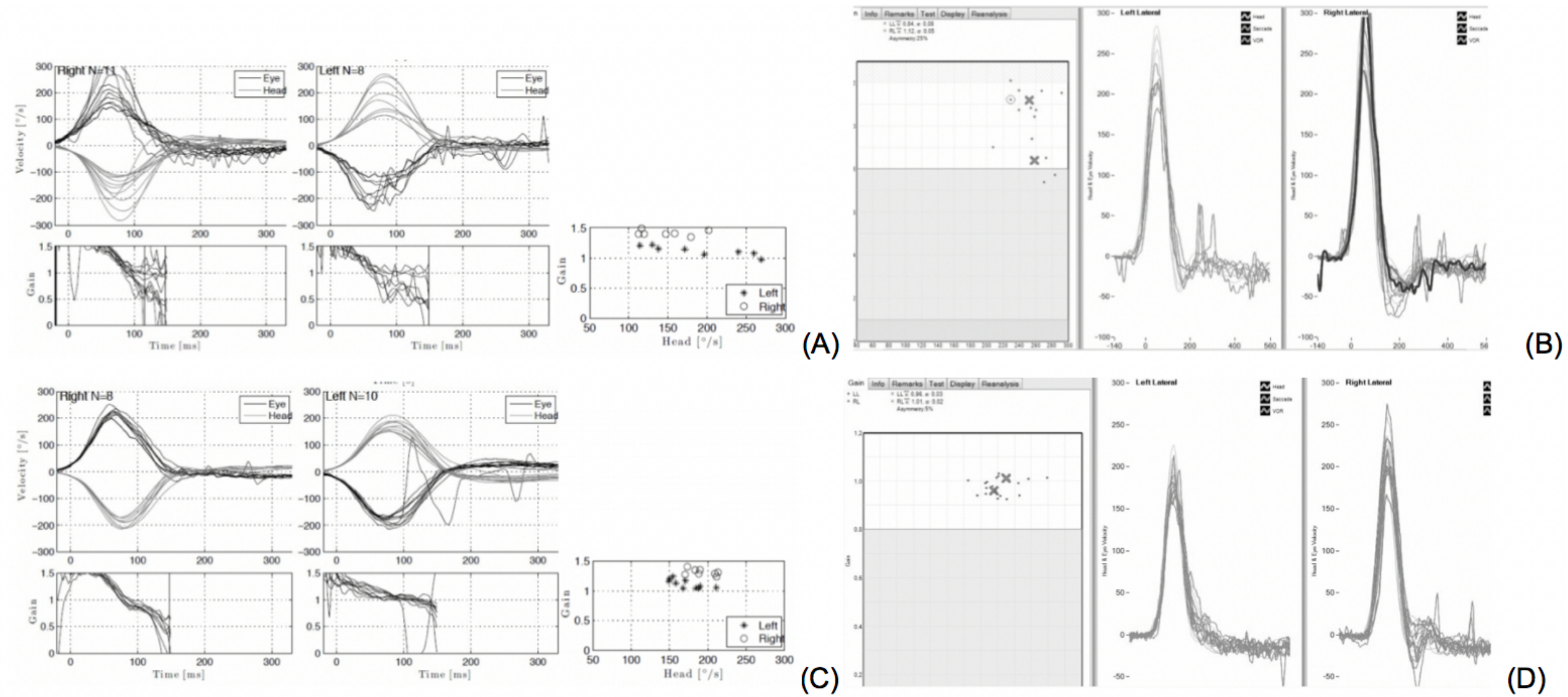

Figure 3. Results from the vHIT among subjects with specific vestibular disorders. (A) The EyeSeeCam results from a posterior BPPV subject. Although minor irregularities can be observed in the eye velocity traces, these appear to be readily symmetrical without covert and overt correctional saccades. (B) ICS Impulse results from same subject with a posterior BPPV . Qualitatively, these results match the results obtained with the EyeSeeCam: no (c)overt saccades were observed. Quantitatively, there are large differences between the systems in absolute gain values and asymmetry. (C) The EyeSeeCam results from a SCDS subject and (D) ICS Impulse of the same subject. USA, 2019.

Nevertheless, this study shows that there is a need for further in-depth comparison of both systems. Moreover, it would be helpful to extract raw data on head and eye velocity traces from both systems and process them for direct comparison of the hardware.

In conclusion, both of these vHIT systems are reliable and good for complementary otoneurological evaluation. They were able to track the VOR reflex gain fast and accurately during high-frequency head movements and can provide useful diagnostic information when implemented in a vestibular evaluation.

The number of tests available for vestibular system evaluation is currently growing. Many studies have shown, and practicing clinicians agree, that there are clear advantages in using and applying the vHIT for evaluating patients with vestibular disorders, in comparison with other tests available. The advantages of this test include lower cost, shorter test time, greater portability and increased patient comfort, compared with other assessments. It is important to clarify that the vHIT is classified as a complementary test for diagnosing vestibular pathological conditions. Because of the small sample size of this study, there is a need for further in-depth comparison of these two systems.

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