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Update VertiGo – light affection of mobile VNG

Abstract: Dizziness is one of the most frequent symptoms in outpatient practices. For the differentiation of peripheral or central pathogenesis of vertigo, history taking and clinical examination with the detection of nystagmus is elementary. The aim of this study was to investigate the effect of lighting for the detection of horizontal vestibular nystagmus while utilizing a conventional webcam. In the proof-of-concept study, caloric induced vestibular nystagmus was recorded with a conventional video-nystagmography and mobile webcam in addition to an external light source. The analysis of recorded data was performed with a self-developed software using computer vision techniques. The self-designed algorithm detected the existence of nystagmus and its direction in several cases.

The experimental webcam-based vestibular nystagmography could be enhanced by improving lighting conditions. Currently, a clinical application for this technique is not approved. Further software improvements are necessary to increase its accuracy.

Keywords: dizziness, vertigo, nystagmus detection, video oculography, nystagmography

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1 Introduction

Dizziness is one of the most common, non-specific symptoms in medicine [1]. Approximately one in three people complain of dizziness at some point in their lives, which could affect daily activities in 20% of patients older than 60 years and increasing up to 50% for over 80-year-olds [2]. The balance disorder can result in social isolation, prolonged absence from work, or drop-attacks causing fractures which can lead to immobility as well as loss of self-determination [3].

An acute vestibular attack can present as rapid onset vertigo with illusory sensation of movement, nausea or vomiting, and gait unsteadiness. The symptoms are often self-limited within days to weeks. The U.S. emergency

departments estimate more than 2 million annual visits and costs of over \$4 billion per year [4, 5]. The importance of determination of peripheral or vestibular pathogenesis of vertigo is the urgency of medical life-threatening intervention in central disorders such as cerebellar infarction or haemorrhage, basilar artery occlusion or vertebral artery. For the determination of vertigo pathogenesis, history taking as well as clinical examination with the detection of a nystagmus is essential [2].

A nystagmus is an involuntary, rapid, rhythmic oscillatory eye movement induced by a dynamic, patterned visual stimulus or malfunction in the vestibular system. Elementary in the detection of a nystagmus are Frenzel spectacles or video-nystagmography (VNG) [6]. According to their existence, direction and movement pattern, the nystagmus can be assigned to being of either primarily vestibular or neurological origin.

Further nystagmus detection tools and vestibular tests exist which could only provide a snapshot of vestibular function [5]. Many experimental nystagmus detection devices are still not integrated in clinical application [7-13]. Additionally, these traditional and contemporary testing tools require hands-on expertise, experience in evaluation of test results, costly equipment and are only available in specialised clinical settings, e.g., clinic or hospital [9-13]. Especially in rural areas, these testing devices or experts are often not available.

A sporadic attack and shortly self-limited episode of dizziness like Ménière's disease, benign paroxysmal positional vertigo (BPPV) or Vestibular Migraine make it unlikely that this episode can be examined and seen at a doctor's appointment. With the aim of creating a self-contained, time and location independent solution for dizzy patients, the feasibility study was continued [14]. The aim of this study was to increase the detection rate of webcam-based video-nystagmography under improved lighting conditions. The obligatory pupil motion profiles were recorded using computer vision techniques while a self-developed algorithm evaluated the existence of nystagmus.

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2 Material and Methods

The experimental setup was adopted from the previous feasibility study [14]. All 20 healthy volunteers negated ear problems or diseases as well as current or previous dizziness symptoms. Microscopic ear inspection was without pathological findings. Conventional video-nystagmography (Diatec, Germany) was performed with all probands in order to assure an absence of a nystagmus without vestibular stimulation, followed by a conventional video-nystagmography (Diatec, Germany) after caloric vestibular testing with water at 44° C for 30 seconds with a 30 ° head inclination position of each ear [15].

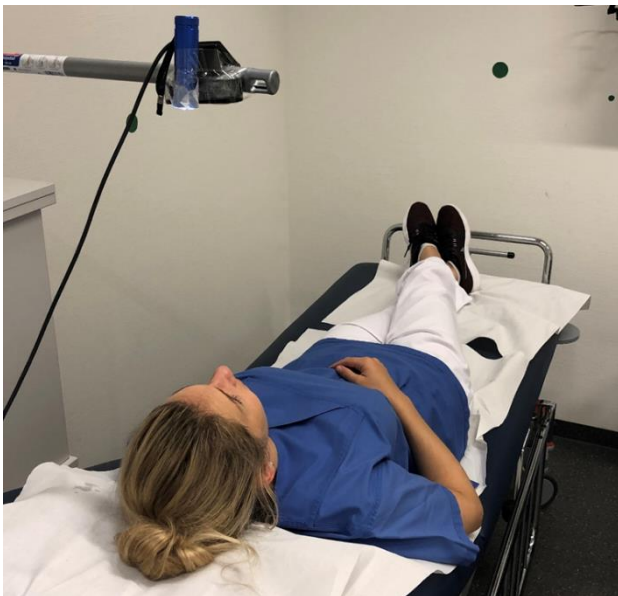


Figure 1: Setup for nystagmus detection via webcam with external light source.

After a recovery period of at least two hours, a further caloric testing was performed in the same manner for each ear. This time, video-nystagmography was recorded using a FullHD webcam (n=40) for 60 seconds with an average amount of around 20 to 25 frames per second of the facial region. An additional video sequence was recorded without caloric stimulation. The used webcam did not contain IR techniques.

The volunteers were focusing on an external light source close to the camera during the recording. For a successful video recording, the face and two eyes needed to be identified frontally in almost every frame within the first 20 seconds of the detection.

The data was saved as a video sequence with a small rectangle cut-out of the eyes. This assured an anonymous data evaluation (Fig. 2).



Figure 2: Anonymized recorded video with a rectangle cut-out bounding the eye regions.

The recorded data was analysed in the same manner as the previous study with a self-developed software which detected eyes and faces by "Facial Landmark Detection" which is integrated in the OpenCV programming library (Open Source Computer Vision Library) [14, 16, 17]. In order to minimize the region of interest, the convex hull of the facial landmarks describing the eye was computed within the bounding rectangle of a single eye (Fig. 2). The cropped eye region was blurred to remove any noise, and eroded to reduce the impact of backlights, i.e., a pixel is set to a local minimum with respect to its neighbouring region. The processed image was then binarized with the intent to have only black and white pixels. This image binarization aimed at separating the iris from the bulbus oculi. Afterwards, the contour of the iris was detected, which was separated by the colour contrast. Next, the pupil position was obtained by calculating the centroid of the detected iris contour. Thus, the applied method for pupil detection assumed that the centre of the iris is the centre of the pupil. The aforementioned binarization of the ocular region used a threshold to set pixels to either black or white. As this threshold was sensitive to the quality of the image, e.g., light conditions and image resolution, the threshold was calibrated using the first 20 images of a given video. Empirical data results have shown that the size of the iris usually took around 50 % of the size of an ocular region which has been detected using Facial Landmark Detection. Accordingly, an iteration over a set of possible threshold candidates was performed and the value which provided a contour of the iris that is closest to 50% of the overall ocular region's size was kept and used for the following pupil detection. The pupil detection provided a sequence of pupil positions with timestamps for each eye (Fig. 3), i.e., a time series of data. For horizontal nystagmus detection the vertical pupil positions were removed. The self-designed algorithm detected nystagmus in a sequence of horizontal pupil positions according to the nystagmus definition defining a fast and slow phase. Nystagmus was distinguished based on the following criteria: whether 1) pupil movement was faster than a predefined threshold value between two frames, 2) the velocity of pupil movement was consistent until a maximum peak has been reached and 3) a fast phase was followed by a slow phase where the pupil moved considerably slower back to the primary point of pupil movement (Fig. 3). The algorithm used predefined threshold values, e.g., defining the minimum distance between the primary point, the minimum velocity of a nystagmus fast phase

and peak of a nystagmus. The threshold values have been examined empirically using the data gathered from the previous research study [14]. These threshold values were adapted in the current study in order to decrease the amount of false positive detections. This reduced the performance on the prior database [14]. The predefined threshold for the occurrence of nystagmus was transferred from the preliminary study and defined that at least two nystagmus in the same direction had to be detected in order to discriminate between the presence or absence of nystagmus.

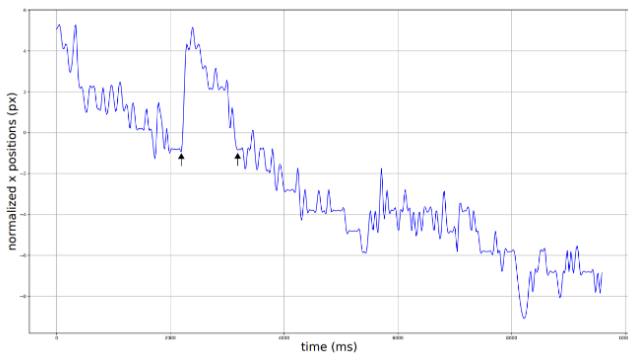


Figure 3: Graph of recorded eye movements with arrows at detected nystagmus.

The descriptive analysis was performed with Microsoft Excel (Microsoft Corporation, Redmond, USA).

3 Results

All probands have shown objective vestibular reaction with the first caloric testing on both ears.

The webcam-based nystagmus detection had identified a single nystagmus in 61.6% of cases. When using the threshold of two nystagmus in the same direction to determine the presence of nystagmus, the software determined 21.6% of data to contain nystagmus.

Regarding the threshold of two nystagmus in the same direction, an accuracy of 50% was analyzed which is the proportion of data which were correctly assessed. Furthermore, 84.61% of the data determined by the software to contain nystagmus were correctly classified. Moreover, a sensitivity of 28.94% was achieved. All subjects reported symptoms of dizziness with an average VAS of 2.9.

Besides the presence of nystagmus, the expected direction of nystagmus was recorded during the caloric vestibular testing. The software assigned the expected direction of nystagmus in 35.89% of cases for single detected nystagmus and 30.76% of cases where it detected nystagmus using the threshold of two nystagmus in the same direction.

Table 1: Contingency table of Nystagmus events regarding the predefined threshold of at least two nystagmus in the same direction

	software	
	positive	negative
positive	11	28
negative	2	19

4 Discussion

Diagnosing the variety of potential causes for dizziness can be difficult in an emergency department setting. The majority of vertigo patients undergo unnecessary testing prior to referral to the correct specialist [3]. The key component in examination of dizziness is the detection of a nystagmus besides history taking, vital signs and gait function [13]. In dependence of their existence, direction and movement patterns, a differentiation between primarily vestibular or neurological pathogenesis can be achieved. This expertise is not routinely available in emergency departments [18].

The examination of eye movement with head impulse testing, and test-of-skew is more sensitive and less costly than early magnetic resonance imaging for stroke diagnosis in acute vestibular syndrome [18, 19]. Conventional, expensive and bulky VNG goggles enabling the recording of eye movements are recommended in emergency departments for the examination of vestibular ocular reflex [18, 8].

Therefore, the inexpensive and easy to handle VNG method via a webcam was tested in a previous study with a limited nystagmus detection rate [14]. This could be affected in individual cases by an insufficient recovery period of 20 minutes after first caloric testing. A further possible issue was a suppressed nystagmus due to fixating the webcam. Therefore, the ENT-specialists and the software could not always detect any nystagmus. With the use of a simple and low-cost penlight the fixation of the eye could be prevented while also improving lighting conditions which increased video quality [20]. Further experimental nystagmus detection trials, which examined the optokinetic nystagmus, experienced the negative influence of inadequate lighting conditions in the recording [13].

In the present feasibility study, it could be shown that mobile nystagmography with a commercial webcam and an external additional light source can improve the detection rate of horizontal vestibular nystagmus. When considering the threshold of two nystagmus in the same direction, an accuracy of 50%, a positive predictive value of 84.61% and a sensitivity of 28.94% were achieved. The self-designed software was adapted in order to decrease the amount of false positive detections. This reduced the performance on the prior dataset

[14]. In the preliminary study without an additional light source and the adapted software, an accuracy of 39.66%, a positive predictive value of 70% and a sensitivity of 17.95% were detected. All subjects of the present feasibility study reported symptoms of dizziness with an average VAS of 2.9.

In comparison to other traditional or contemporary nystagmography gadgets, the inexpensive and easy to handle equipment has many advantages: disclaim of an additional goggle, mobile phone or other bulky device, and no detailed calibration or professional expertise in application is necessary. This saves time, budget and personnel [7-13]. Other nystagmography methods seems to be limited in future emergency application for vestibular testing due to head fixation [13].

In comparison to prior experimental mobile nystagmography devices, the unique methods of VertiGo (a combination of webcam and self-designed software algorithms) make an assessment of existence or absence of eye movement as well as assignment of the beating direction of the horizontal nystagmus possible [7-13].

The digitalization of neurotologic tests provides the chance for remote assessment which may help to overcome the lack of expertise outside metropolitan areas in the future [21]. These proof-of-concept findings suggest that a portable video-nystagmography could offer a recording of a video sequence at any time and place. In future, recordings could be presented at a further consultation of a specialised doctor or as a screening device in the triage of an emergency department as well as telemedical support for rural areas without using unsatisfying standard videoconferencing tools [21]. Symptom tracking of sporadic onset of vertigo episodes could be possible without unhandily and extravagant accessories [12].

In the experimental setting, the vestibular nystagmus detection could be enhanced in comparison to the preliminary study. There are a number of limitations to this study and further improvements are required to develop the software from a research tool into a reliable investigation tool in primary or secondary care. Because this was an update of a feasibility study, our sample size was limited to 20 patients [14]. Moreover, the inexpensive investment of a commercial webcam with a maximum rate of 30 frames per second could limit the fundamental frequency of nystagmus detection. Analogous to the contemporary CAVA system, the slow phase of velocity of a nystagmus which quantifies the ocular movement was not possible to calculate [12]. Additional interferences are experienced with fatigue and resulting nictitating of eyes, dark coloured iris as well as reflection or extensive eye make-up [12, 13].

In future, further improvements and tests of the software are necessary to increase its accuracy and reduce interferences. The aim is to develop a low-budget 24/7 available and easy to handle examination tool for patients in primary and secondary care. VertiGo could someday be used in the acute setting, for

instance, to help non-specialist physicians to diagnose strokes in patients with acute vertigo or dizziness which ensures adequate treatment.

In future trials, it should be evaluated whether a machine learning algorithm can be trained to detect horizontal nystagmus from a recorded time series of data, and to track the eye pupils. Furthermore, mobile IR techniques could be evaluated for nystagmus detection. In this context, an increased amount of gathered data is essential to evaluate whether a machine learning algorithm can be developed. In addition, we want to extend the study to evaluate whether vertical or rotating eye movements can be detected as well.

Author Statement

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