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Abstract

Background: Observing eye movements during episodic vertigo attacks is crucial for accurately diagnosing vestibular disorders. In clinical practice, we commonly encounter cases without vertiginous/dizziness symptoms or clear abnormal findings during outpatient examination.

Objective: To report a case in which a novel device integrating an infrared camera with 3D-printed goggles was useful in diagnosing vestibular disorders.

Methods: We developed a device that integrates a commercially available mini-infrared charged-coupled device (CCD) camera with 3D-printed goggles, enabling patients to record their eye movements during vertigo attacks at home using a smartphone and to share the recordings with their physicians.

Results: A man in his 40s with episodic vertigo visited our hospital. Initial assessments using infrared video Frenzel glasses showed no spontaneous or positional nystagmus, and oculomotor-vestibular function tests revealed no abnormalities. Based on the videos recorded by the patient using our system, geotropic direction-changing positional nystagmus was observed, and lateral semicircular canal-type benign paroxysmal positional vertigo was diagnosed. Treatment with the Gufoni maneuver alleviated the vertigo and nystagmus.

Conclusions: Our system aids in the diagnosis of vestibular disorders by enabling the capture of symptomatic eye movements outside of clinical settings. Additionally, it shows promise for use in telemedicine and emergency situations, offering a practical solution for remote monitoring and timely diagnosis.

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Abstract

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Conclusion: Our system aids in the diagnosis of vestibular disorders by enabling the capture of symptomatic eye movements outside of clinical settings. Additionally, it shows promise for use in telemedicine and emergency situations, offering a practical solution for remote monitoring and timely diagnosis.

Keywords: dizziness; vertigo; smartphone; BPPV; telemedicine

INTRODUCTION:

Vertigo/dizziness is a common ailment experienced at all ages, with an estimated lifetime prevalence of 3–10% [1]. It is symptomatic of peripheral vestibular, central, and psychogenic disorders and circulatory dysfunction, as well as life-threatening conditions, such as cerebrovascular disease, making accurate diagnosis clinically significant [2,3]. Even when not life-threatening, episodic vertigo attacks accompanied by nausea and vomiting can substantially impair an individual's quality of life [4].

Recently, the use of telemedicine has expanded across various fields owing to the rapid spread of information and communication technology, the widespread use of smartphones and tablets, and advancements in data communication technology [5]. The COVID-19 epidemic further accelerated the adoption of telemedicine in clinical care [6]. Consequently, the use of smartphones for telemedicine in vertigo treatment has increased [7,8]. For example, Shah et al. used smartphone-recorded eye-movement videos to diagnose benign paroxysmal positional vertigo (BPPV) [9]. Additionally, we developed a recording and analysis system for video head-impulse testing using smartphones [10]; this system was found to be effective when field physicians collaborated with remote specialists, especially in emergencies.

Observing eye movements during vertigo attacks is critical for accurately diagnosing recurrent vestibular disorders [11]. However, in clinical practice, we often encounter cases without symptoms or clear abnormalities during outpatient examination. Independent at-home recording of eye movements during vertigo attacks benefits patients and physicians. Although smartphone recordings have been used to diagnose conditions such as Meniere's disease [12], they may not always capture nystagmus adequately owing to suppression by the patient's gaze.

By integrating a commercially available mini-infrared charge-coupled device (CCD) camera with 3D-printed goggles, we devised a method that allows patients to record eye movements during vertigo attacks in darkness at home and share the recordings with their physicians. Herein, we report a case demonstrating the diagnostic utility of this method.

METHODS:

Ethical considerations

This study was approved by the Medical Research Ethics Committee of Mejiro University (approval number: Medical 21-005). Written informed consent was obtained from the patient after providing sufficient explanation regarding protecting personal information. The CARE EQUATOR guideline was followed.

Development of the device

A mini-CCD camera equipped with an infrared imaging mode was selected to capture spontaneous nystagmus under low-light conditions (Wireless Mini Camera Model: Q15; Shenzhen Aobo Technology Co., Ltd.) (Fig. 1a). The camera, costing approximately $25 (US), boasts a resolution of 1920 × 1080 pixels/inch, a shooting angle of 150°, video encoding of H.264, and measures 32.5 mm on each side. Using Wi-Fi to start and stop recordings, patients can simultaneously and conveniently produce video and audio recordings using their smartphones.

Slots were placed inside the goggles on the left and right sides, and the center of the camera was inserted in the slot aligned with the line of sight (Fig. 1b). Both eyes were simultaneously photographed using two cameras. We designed the goggles using Tinkercad, an online 3D modeling tool, an AFINIA H+1 3D printer (Microboards Technology Inc.) (Fig. 1c). Black filament AFINIA ABS Premium Plus (Microboards Technology Inc.) was used for printer output to preserve the darkness (Fig. 1d). Eighteen pairs of goggles were produced, with filament costs of approximately $13 (US) /pair. The construction data for the 3D printer are available for download (https://drive.google.com/file/d/17z9vB0zNXqqtIAJdmySHZPnHK6e_-qxQ/view?usp=drive_link). These data can be used to create goggles compatible with other mini-CCD cameras.

Operation of the device

To operate the CCD camera, the patient installed an application (HDSPCAM APP) on his smartphone or tablet. He paired the smartphone/tablet with the camera and selected the infrared imaging mode. During vertigo attacks, he placed the camera in the goggles, pressed the start button on the paired smartphone/tablet, and placed the goggles on his face. The captured images were automatically stored via Wi-Fi on the patient's smartphone/tablet (Fig. 2).

RESULTS:

Case Presentation

A man in his 40s with episodic vertigo visited our hospital. Initial assessments using infrared video Frenzel glasses showed no spontaneous or positional nystagmus, and oculomotor-vestibular function tests revealed no abnormalities; therefore, a definitive diagnosis was not reached. We rented him our self-made 3D-printed goggles and an infrared CCD camera to record the patient's eye movements during dizziness. We also asked him to verbally record his posture when he changed positions (e.g., supine, lower left, supine, and lower right).

Assessment results

Reviewing the videos, geotropic direction-changing positional nystagmus was observed, and lateral semicircular canal-type BPPV was diagnosed. (Fig. 3) The affected ear was identified from the nystagmus's appearance, direction, and intensity in different positions using the audio recordings. Treatment with the Gufoni maneuver alleviated the vertigo and nystagmus.

DISCUSSION:

Episodic vertigo attacks can occur at any stage of daily activity, but are not always present during examination. In this case, auditory, oculomotor, or vestibular functions were ostensibly normal during the outpatient examination, preventing a diagnosis. In cases of episodic vertigo, differentiating between BPPV, vestibular migraine, Meniere's disease, and other disorders is necessary. Our device captures eye movements during vertigo attacks, allowing accurate diagnosis and appropriate treatment by physicians.

The goggles were printed with an adhesive filament to secure the CCD camera and maintain their shape despite their complex structure. However, each printing required approximately 10 h. Optimizing the design of the goggles' interior and improving printer performance might shorten production time. Alternatively, eye movements during vertigo attacks can be captured via video recording using a smartphone. Using this method, Kıroğlu et al. diagnosed Meniere's disease in patients with vertigo attacks [12]. For vertigo diagnosis, confirming spontaneous nystagmus under non-gazing conditions is crucial [13]. However, when recording with a smartphone, nystagmus may be suppressed in bright conditions, as people tend to gaze at ambient light or the camera lens, making it difficult to capture eye movements in the dark.

Previous studies used a deep-learning system [14] and smartphone application [15] to detect nystagmus.

Advances in these technologies and their integration with other devices will aid in the assessment of smartphone-captured eye-movements at home and detection of nystagmus.

As a potential adaptation to telemedicine, remote specialists have used eye movements captured on a smartphone to evaluate BPPV. Compared to infrared CCD cameras, smartphones are more portable and less expensive. Commercially available infrared CCD cameras with Wi-Fi and 3D-printed goggles can be used for online medical care by dizziness specialists and physicians in emergency medicine.

Limitations

The low resolution and close-up capability of the videos recorded using our mini-infrared CCD camera were insufficient for analyzing the torsional components of nystagmus because the iris pattern was unclear. However, the direction and intensity of the nystagmus can be easily determined, making the camera a reasonable diagnostic tool. Three-dimensional analysis may be possible depending on the camera's performance.

Conclusion

We developed a cost-effective home nystagmus monitoring system using a mini-infrared CCD camera and 3D printer. This system will potentially improve the diagnosis of vestibular disorders by enabling the capture of symptomatic eye movements outside of clinical settings. Additionally, it shows promise for use in telemedicine and emergency situations, offering a practical solution for remote monitoring and timely diagnosis.

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Conflicts of Interest: The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Abbreviations: BPPV: benign paroxysmal positional vertigo; CCD: charged-coupled device

Data availability: The data that support the findings of this study are available from the corresponding author (M.N.) upon reasonable request.

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Figure Legends

Fig 1. The mini-infrared charged-coupled device (CCD) camera and handmade goggles used to mount the camera.

(a) A mini-infrared CCD camera. (b) The mini-infrared CCD camera can be set on each side of the goggles. (c) Design diagram created using CAD software. (d) Goggles output by a 3D printer.

Fig 2. Use of the handmade goggles.

The goggles were used to record eye movements during vertigo at home, and the videos are saved on a smartphone.

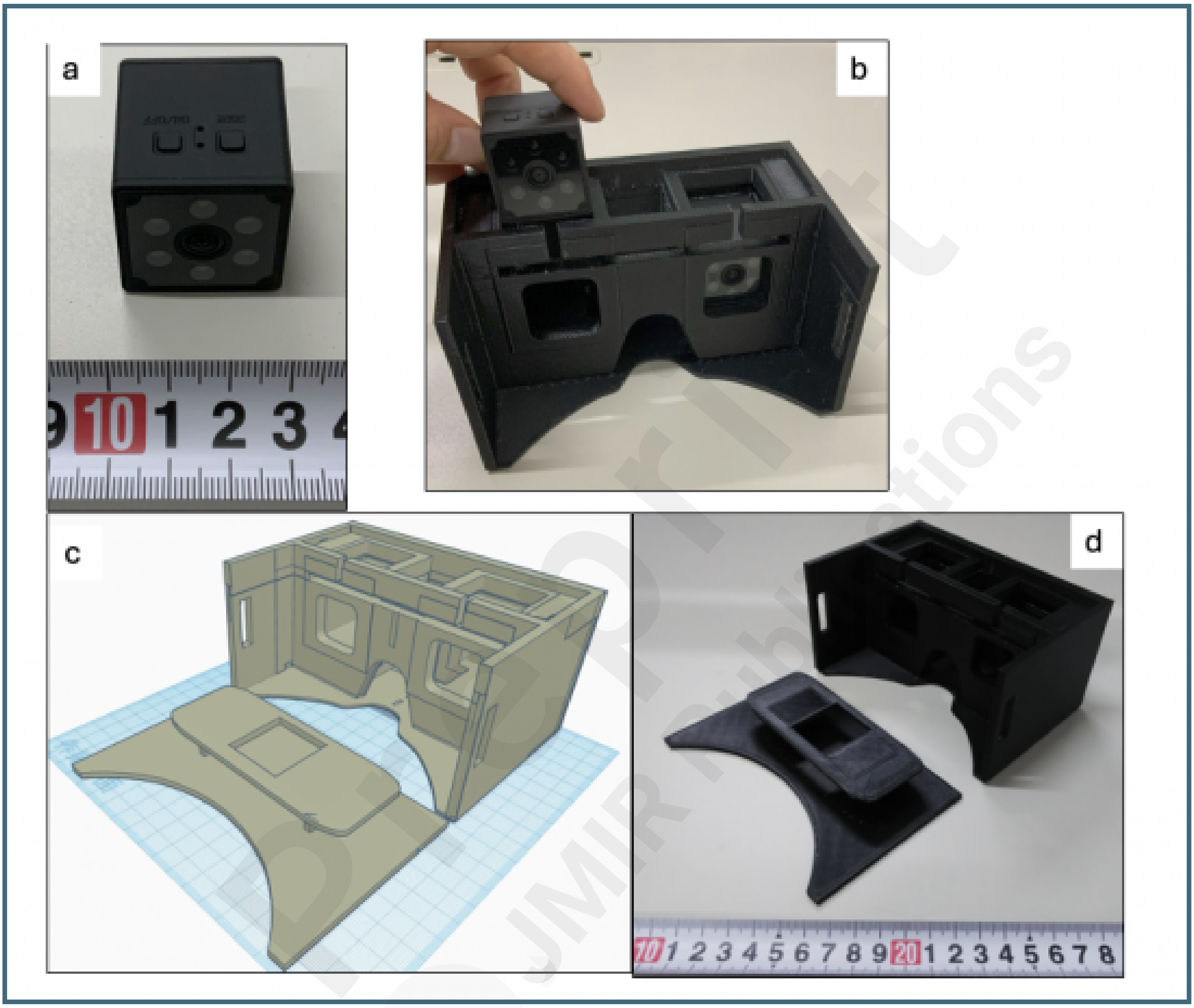
Fig 3. Eye movements recorded by the patient during a vertigo attack. Geotropic direction-changing positional nystagmus was observed.

(a) A still image of the video recorded using the infrared charged-coupled device camera. (b) Because we cannot show video clips in this paper, we instead show the waveforms of the eye movements. The ocular position was measured using the corneal reflex method to present the recorded nystagmus. OpenCV (Intel Corporation, Santa Clara, CA, USA) was used for image processing. H: horizontal component. V: vertical component.

Supplementary Files

Figures

The mini-infrared charged-coupled device (CCD) camera and handmade goggles used to mount the camera. (a) A mini-infrared CCD camera. (b) The mini-infrared CCD camera can be set on each side of the goggles. (c) Design diagram created using CAD software. (d) Goggles output by a 3D printer.



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