2024 46th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) | 979-8-3503-7149-9/24/$31.00 ©2024 Authors | DOI: 10.1109/EMBC53108.2024.10781586

“EpilepSee” Glasses: A Wearable Seizure Prevention Device for Photosensitive Epilepsy

George Crooks*, James Perks*, Frances Gawne*, Hasan Ali, Harrison Steel,
Timothy Denison *(Senior Member, IEEE)* and Antonio Valentin

***Abstract*—Temporarily reducing retinal stimulation when exposed to a hazardous photic stimulus by activating a rapidly responding electrochromic material could provide a novel seizure prevention method, referred to as the “EpilepSee Glasses”, for people with photosensitive epilepsy.**

Analysis of an electroencephalogram (EEG) recording has shown reduced photoparoxysmal responses when exposed to flashing light whilst wearing a pair of glasses with one lens covered by an electrochromic material. By characterising the variation of the light seen in a user’s field of vision in real time, and exploiting the fact that a stimulus must, on average, be present for at least 1 second to cause a seizure, the glasses’ lens only needs to activate upon detection of a potentially harmful stimulus. This means that when the optical environment is deemed safe by the device, the user will experience minimal change to their quality of life.

Further development could result in this proof-of-concept device evolving into a simple, affordable solution for non-invasive seizure prevention, filling an otherwise unexplored gap in treatment methods.

***Index Terms*—electrochromic, epilepsy, glasses, photoparoxysmal, photosensitive, seizure, wearable**

I. INTRODUCTION

Photosensitive epilepsy is a neurological disorder that affects around 2 million people worldwide [1], [2]. It is characterized by reflex seizures in response to specific photic stimuli. Photic stimuli appear in the form of flashing lights or patterns, and often possess a combination of the following properties: high brightness and contrast, specific flash frequencies (most seizures occur in the range of 3-60 Hz), and deep, saturated red colors [3].

About 30% of the epileptic population does not respond to anti-seizure medication [4], leading the industry to find alternative methods for preventing seizures. Some current treatments include deep brain stimulation [5], Vagus nerve stimulation [6], and brain surgery [7]. However, these all have significant limitations in terms of cost and risks of surgery involved [8], [9]. Other strategies include avoidance of potential triggers, or covering one eye when in the presence of a triggering stimulus [10], [11], but this can be socially isolating and unreliable. One other type of treatment is the use of “Z1” blue lenses in glasses [12], which severely restrict the intensity of light that passes through. However, this is highly impractical as it strongly limits the person’s vision.

This paper details the proof-of-concept of a non-invasive, wearable device designed to optically isolate those with photosensitive epilepsy from harmful stimuli. An initial electroencephalogram (EEG) test showed the viability of the device. The key requirements of the device were defined as follows:

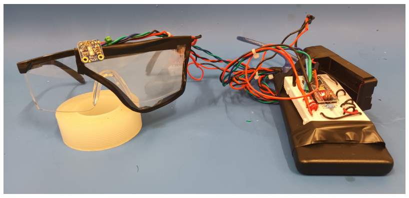
1) To detect hazardous flashing, as defined in section II-C.
2) To reduce retinal stimulation by activation of an electrochromic film over one lens such that no seizure occurs.
3) Completion of the detection and actuation stages in less than the average seizure onset time of 1.85 seconds [13].

II. MATERIALS AND METHODS

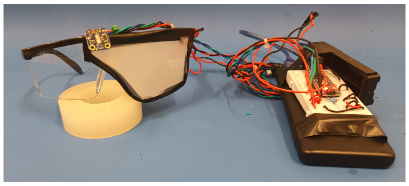
A. Prototype Device Architecture

The EpilepSee glasses prototype, shown in both its “transparent” and “opaque” states in Figure 1, is a pair of safety glasses with a light intensity sensor fixed centrally, and one lens covered in an electrochromic film.

A high-precision Adafruit VEML7700 light sensor measures the intensity of ambient light, in lux (lumens per square meter), at a rate of 40 Hz. Outputting this data to an Arduino Nano v3.0 allows the progression of light intensity seen by the



(a) Transparent state.



(b) Opaque state.

Fig. 1. Front view of the EpilepSee glasses prototype. Subfigure (a) shows the device in a transparent state. Subfigure (b) shows activation of the electrochromic film to induce the opaque state.

---

*G. Crooks, J. Perks and F. Gawne have contributed equally to this work as lead co-authors.

The authors G. Crooks *(Corresponding Author)*, J. Perks, F. Gawne, H. Ali, H. Steel and T. Denison are with the Department of Engineering Science, University of Oxford (email: george.crooks@univ.ox.ac.uk).

F. Gawne is with the Department of Medical Physics and Biomedical Engineering, Univeristy College London (email: frances.gawne.23@ucl.ac.uk).

A. Valentin is with the Institute of Psychiatry, Psychology and Neuroscience, Kings College London; Alder Hey’s Children Hospital, Liverpool, and King’s College Hospital, London (email: antonio.valentin@kcl.ac.uk).

wearer to be analyzed by the Arduino, which runs an algorithm later explained in section II-C.

If the light scheme is deemed to be dangerous, then the Arduino outputs a signal to the control box of the electrochromic material, triggering the actuation of the film. The construction and operation of the film is detailed below.

B. Electrochromic Film

Polymer Dispersed Liquid Crystal (PDLC) films can reversibly switch between "opaque" and "transparent" states upon the application of a high-frequency AC voltage. This ability is due to the presence of small, randomly-oriented liquid crystal droplets that are suspended in a polymer matrix. Naturally, this scatters the light that passes through, resulting in the appearance seen in Figure 1b that is referred to as the opaque state.

However, when stimulated (in this case with an AC signal of approximately 1 kHz and a peak-to-peak voltage of 20 V), the liquid crystals align in such a way that they match the refractive index of the polymer matrix [14]. This results in a state that can be clearly seen through, and is referred to as the transparent state.

With the time taken for the change from transparent to opaque having been recorded at less than 10 milliseconds, the switching time is deemed negligible compared to the detection time required [15].

C. Light Sensor and Flash Detection Algorithm

The VEML7700 light sensor uses a highly sensitive photodiode with a spectral response close to that of the human eye [16]. The sensor integration time is set to the shortest available duration of 25 ms, over which received light is integrated to calculate an ambient light measurement in lux. This light sensor is connected to an Arduino which runs the flash detection algorithm.

The flash detection algorithm is a critical component of the EpilepSee glasses which, in real time, detects hazardous light flashes that could cause a seizure. A flash can be defined by an increase in light intensity followed by a decrease, or a decrease followed by an increase. To detect flashes, the EpilepSee glasses algorithm follows a similar method to that used in [17], with modifications to use measurements from a light sensor instead of luminance values calculated from screen pixels. As in [17], local maxima and minima from the light sensor measurements are stored in a vector. The lux values for the maxima and minima, together with the time between each extremum, are used to quantify the changes in light intensity over time. Each time the vector is updated with a new extremum, the following criteria are used to determine if the flash sequence is hazardous:

1) A total of 3 flashes occur in under 1 second.
2) The magnitude of the change in light intensity between every subsequent maximum and minimum in the flash sequence is greater than 100 lux.

Provided both criteria 1 and 2 are met, a hazardous flash sequence is deemed to have occurred. Upon detection of a hazardous flash, the microcontroller turns the lens from a transparent to an opaque state. The lens is held in the opaque state until 5 seconds after flashing has ceased.

D. Preliminary Device Testing

Preliminary testing to show the reduction of transmitted light intensity through the PDLC film as it changed from transparent to opaque states was carried out prior to EEG testing. Light intensity measured by the VEML7700 sensor on the glasses was compared to readings from a second identical light sensor placed immediately behind the electrochromic film to mimic the variation of light received by a human eye. The difference in light intensity received by each sensor when the device is exposed to a flashing light source is shown in Figure 2, and a discussion of the results can be found in section III-A.

E. Proof-of-Concept Test: Photoparoxysmal Response

The participant was one of the authors: a healthy, able-bodied, neurotypical, 21-year-old male, and provided informed consent prior to the study. This test was conducted in compliance with the Declaration of Helsinki.

The experiment consisted of one session at King's College Hospital. An EEG setup was placed on the participant's head with electrodes located according to the 10-20 system [18]. The participant was asked to lie in the supine position. Brain activity was detected via the EEG electrodes, where the signal was then filtered and amplified (Nicolet v32 Amplifier, Natus). The EEG signals were then recorded using NicoletOne HL7 software (Natus).

A standard Intermittent Photic Stimulation (IPS) test was performed under 5 different conditions, with a rest period of 90 seconds between each test. Each test presented flashing light at the frequencies: 1, 2, 6, 8, 10, 15, 18, 20, 25, 30, 40, 50, and 60 Hz, each for a duration of 8 seconds. The conditions of each test performed are as follows:

- Binocular vision - both eyes open.
- Monocular vision - left eye covered by left hand.
- Monocular vision - right eye covered by right hand.
- Binocular vision - both eyes open.
- Wearing the EpilepSee glasses prototype.

The EpilepSee glasses were held in the opaque state for the duration of the experiment.

Signals recorded from the O1 and O2 electrodes were extracted and a Power Spectral Density (PSD) was generated for each test on both electrodes using EEGLAB (Matlab, 2022b). All further analysis was performed on Matlab (2022b). Data for 1 Hz and 2 Hz were omitted as they fall outside the sensitive frequency region for photosensitive epileptic people. Stimulation with the first binocular vision condition was taken as the control, as it resembles exposure to unexpected stimuli. The data from the second binocular vision condition was not used in the analysis as the condition's purpose was to remove bias before performing the test with the glasses. The power of the driving frequencies in the PSD for the rest of the test cases were normalized by the power of the driving frequencies in the PSD for the binocular stimulation case.

III. Results

A. Preliminary Device Testing Results

As shown in Figure 2, even when in the transparent state, there is around a 20% reduction in light intensity received by the sensor behind the film compared to the sensor on the front of the glasses. Upon actuation (sample 60), a clear step change can be seen, showing successful detection of the flashing light and actuation of the PDLC lens. However, the light intensity received by the second sensor is only reduced by a further 8%. It should be noted that the 8% reduction is of the combined ambient light and flashing stimulus. Therefore the reduction of the flashing light alone is likely to be far more significant. Some studies have shown a reduction in transmission upon switching of up to 70% [19]. An alternative type of electrochromic material that could provide these higher reductions in transmitted light intensity is detailed in IV-B1.

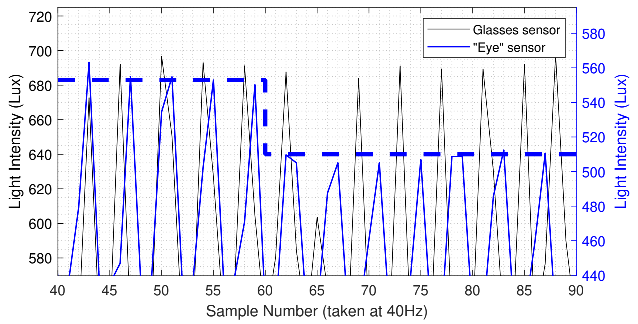


Fig. 2. Light intensity (lux) reduction against sample number, showing actuation of the PDLC lens using the light sensor and flash detection algorithm. The black line shows the variation of light intensity detected by the sensor on the glasses. The solid blue line shows the light intensity detected by the second sensor behind the electrochromic film, mimicking the light intensity that the eye would see. The dashed blue line highlights the step change in the maximum intensities detected by the "eye" sensor.

B. Proof-of-concept test: Photoparoxymal Response Results

The average PSD in the left and right visual cortices under the "wearing the glasses" condition were 60.5% and 78.3% of the control condition respectively (Table I). Both visual cortices saw the largest reduction in PSD in the "wearing the glasses" condition at 40 Hz flash frequency. There were instances, however, in both cortices where there was an increase in neural activity when wearing the glasses compared to the control condition (Figure 3).

It is seen that average PSD under the "wearing the glasses" condition matches closer to the "left eye covered" condition than the "right eye covered" condition (table I). The similarity is to be expected as the opaque lens of the glasses covers the left eye. Notably the glasses are less effective at reducing stimulation compared to either covering the left or right eye. This difference is likely due to the mechanism by which the PDLC lens appears opaque, which involves randomly scattering light instead of fully blocking it. Therefore the reduction in retinal stimulation is less when wearing the glasses than when covering the eye by one's hand.

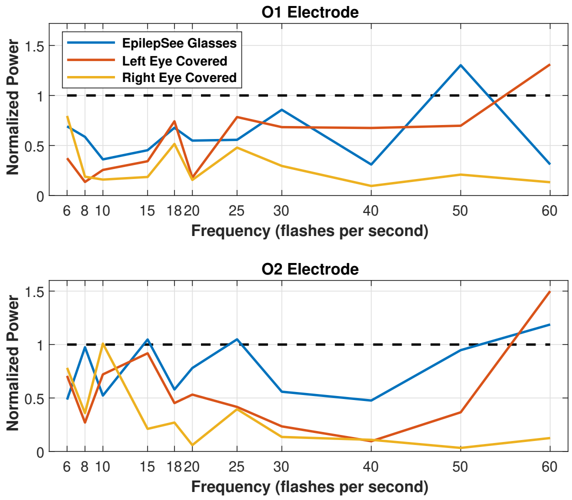


Fig. 3. O1 and O2 electrode PSD normalized with respect to the PSD response for binocular vision (both eyes open) at each frequency used in the IPS test. The black dotted line represents a PSD response equal to that of both eyes open (a normalized PSD of 1). All points below the black dotted line show a reduced PSD relative to the PSD response with both eyes open. The PSD response while wearing the EpilepSee glasses, with the left eye covered, and with the right eye covered are plotted in blue, orange, and yellow respectively.

TABLE I

O1 AND O2 ELECTRODE PSD NORMALIZED WITH RESPECT TO THE BINOCULAR (BOTH EYES OPEN) PSD RESPONSE AT EACH FREQUENCY USED IN THE IPS TEST. THE MEANS OF THE NORMALIZED PSD VALUES ACROSS THE FREQUENCIES USED IN THE IPS TEST ARE SHOWN BELOW.

	Both Eyes Open	With EpilepSee Glasses	Left Eye Covered	Right Eye Covered
O1	1.00	0.605	0.562	0.292
O2	1.00	0.783	0.565	0.317

IV. Discussion

A. Limitations

Although the proof-of-concept test drew promising results, it is important to state that certain methodical aspects should be improved for future studies. Firstly, only one participant was tested with the protocol performed for one iteration in a single session. Therefore, it is important that future work is done on a larger population. Secondly, the participant had no neurological disorders. As the device is intended for an epileptic population, it is imperative for later testing to be conducted on photosensitive epileptic people, to ensure the device's safety and effectiveness. Future testing should also test long-term effects of using the glasses. Another limitation is that the IPS test does not fully represent the real-life environment that the glasses would be used in.

B. Further Development

1) Alternative Electrochromic Materials: PDLC film provided an accessible and affordable solution for use in the prototype described. However, as noted, the reduction in transmitted light intensity when in the opaque state was less than desired, due to the mechanism described which causes the opaque appearance.

A less developed emerging technology uses a pair of electrochromic metal oxide compounds to achieve color changes upon an applied DC voltage. A pair of metal oxide compounds are selected that undergo color changes during reduction-oxidation (redox) reactions and are separated by an electrolyte layer [20].

Benefits of the metal oxide pair electrochromic materials include:

- Continuous variability of transmissivity, rather than discrete switching between transparent and opaque
- Choice to bias absorption of particular wavelengths of light which could be more harmful to users than others

However, at the time of writing, metal-oxide electrochromic materials are not yet suitably developed for application in this device. This is mainly due to the switching speed, which is in the order of seconds, not milliseconds, as is needed for this speed critical application.

2) Light Sensor and Flash Detection Algorithm: The implementation described in section II-C is sufficient for a proof-of-concept. However, a flash detection system suitable for wearing the EpilepSee glasses day-to-day, under a variety of lighting conditions, would require several improvements.

The VEML7700 light sensor takes lux measurements at a maximum frequency of 40 Hz. As stated by Nyquist's theorem, it is necessary to sample at a rate at least twice the highest frequency in the signal to avoid aliasing. The VEML7700 is therefore unsuitable for detecting flashes over 20 Hz. An ideal sensor would sample at a rate at least twice the highest frequency of flashing which could cause a seizure.

The 100 lux threshold used in the flash detection criteria was chosen to detect flashes used in the preliminary device testing described in II-D. A fixed threshold in lux is unlikely to be suitable for the varying lighting conditions which may be encountered by a person wearing the EpilepSee glasses. Further research is required to determine an appropriate and safe threshold to define a hazardous flash.

Notably, the suggested flash detection algorithm does not incorporate colors or patterns. Future research could investigate using a camera instead of a light sensor. This would allow both color and patterns to be included when determining if a visual stimulus is hazardous. An additional benefit of a camera video feed would be a more direct implementation of algorithms from existing literature such as [17], [21], which have been designed to screen video content for hazardous flashes.

V. CONCLUSION

This paper presented a proof-of-concept for a novel seizure prevention device for patients with photosentive epilepsy. EEG testing has shown reduced photoparoxysmal responses while wearing the device. These preliminary results suggest promising feasibility for the device to be developed further in future research.

REFERENCES

[1] (2022) Photosensitve epilepsy. Epilepsy Action. Accessed: 10/2022. [Online]. Available: https://www.epilepsy.org.uk/info/triggers/photosensitive-epilepsy

[2] (2023) Epilepsy. World Health Organisation. Accessed: 01/2024. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/epilepsy

[3] R. S. Fisher, J. N. Acharya, F. M. Baumer, J. A. French, P. Parisi, J. H. Solodar, J. P. Szaflarski, L. L. Thio, B. Tolchin, A. J. Wilkins, and D. Kasteleijn-Nolst Trenité, "Visually sensitive seizures: An updated review by the epilepsy foundation," *Epilepsia*, vol. 63(4), pp. 739–768, 2022.

[4] S. Lee, "Old versus new: Why do we need new antiepileptic drugs?" *Journal of epilepsy research*, vol. 4, pp. 39–44, 2014.

[5] V. Salanova, "Deep brain stimulation for epilepsy," *Epilepsy & Behavior*, vol. 88, pp. 21–24, 2018.

[6] E. Ben-Menachem, "Vagus-nerve stimulation for the treatment of epilepsy," *The Lancet Neurology*, vol. 1(8), pp. 477–482, 2002.

[7] S. Wiebe, "Brain surgery for epilepsy," *Lancet*, vol. 362 Suppl, pp. s48–9, 2004.

[8] E. Ben-Menachem, K. Hellström, and D. Verstappen, "Analysis of direct hospital costs before and 18 months after treatment with vagus nerve stimulation therapy in 43 patients," *Neurology*, vol. 59(6_suppl_4), pp. S44–S47, 2002.

[9] (2018) Risk and benefits of epilepsy surgery. Epilepsy Foundation. Accessed: 10/2022. [Online]. Available: https://www.epilepsy.com/treatment/surgery/risks-and-benefits

[10] Z. V. Okudan and Çiğdem Özkara, "Reflex epilepsy: triggers and management strategies," *Neuropsychiatric Disease and Treatment*, vol. 14, pp. 327–337, 2018.

[11] A. Covanis, S. R. G. Stodieck, and A. J. Wilkins, "Treatment of photosensitivity," *Epilepsia*, vol. 45(s1), pp. 40–45, 2004.

[12] G. Capovilla, A. Gambardella, G. Rubboli, F. Beccaria, A. Montagnini, U. Aguglia, M. P. Canevini, S. Casellato, T. Granata, F. Paladin, A. Romeo, G. Stranci, P. Tinuper, P. Veggiotti, G. Avanzini, and C. A. Tassinari, "Suppressive efficacy by a commercially available blue lens on ppr in 610 photosensitive epilepsy patients," *Epilepsia*, vol. 47(3), pp. 529–533, 2006.

[13] G. Chartrian, E. Lettich, L. Miller, and J. Green, "Pattern-sensitive epilepsypart: 1. an electrographic study of its mechanisms," *Epilepsia*, vol. 11(2), pp. 125–224, 1970.

[14] S. Bronnikov, S. Kostromin, and V. Zuev, "Polymer-dispersed liquid crystals: Progressin preparation, investigation, and application," *Journal of Macromolecular Science*, vol. 52, p. 1718–1735, 2013.

[15] F. Bruyneel, H. De Smet, and A. Calster, "Reduction of the switching time of polymer-dispersed liquid crystal using field oriented addressing," *Electron Device Letters, IEEE*, vol. 23, pp. 401 – 403, 08 2002.

[16] "VEML7700 datasheet," Vishay Semiconductors, Apr. 2022. [Online]. Available: https://www.vishay.com/docs/84286/veml7700.pdf

[17] L. Carreira, N. Rodrigues, B. Roque, and M. P. Queluz, "Automatic detection of flashing video content," in *2015 Seventh International Workshop on Quality of Multimedia Experience (QoMEX)*, 2015, pp. 1–6.

[18] H. Jasper, "The ten-twenty electrode system of the international federation," *Electroencephalography and Clinical Neurophysiology*, vol. 10, pp. 371–375, 1958.

[19] N. Nasir, H. Hong, M. A. Rehman, S. Kumar, and Y. Seo, "Polymer-dispersed liquid-crystal-based switchable glazing fabricated via vacuum glass coupling," *RSC Adv.*, vol. 10, pp. 32 225–32 231, 2020. [Online]. Available: http://dx.doi.org/10.1039/D0RA05911K

[20] W. Wu, M. Wang, J. Ma, Y. Cao, and Y. Deng, "Electrochromic metal oxides: Recent progress and prospect," *Advanced Electronic Materials*, vol. 4, no. 8, p. 1800185, 2018. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/aelm.201800185

[21] R. Tripathi, T. Barwaniwala, V. Kesarkar, S. Patil, and M. Trivedi, "Detection of flashy segment in youtube videos using computer vision technique to prevent seizure in epilepsy patients," in *2023 8th International Conference on Communication and Electronics Systems (ICCES)*, 2023, pp. 1544–1548.