Received: 29 July 2025 | Revised: 13 October 2025 | Accepted: 14 October 2025

DOI: 10.1111/epi.18702

Epilepsia®

SPECIAL REPORT

Visually-provoked seizures: Consensus of the Epilepsy Foundation Working Group

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Abstract

In 2005, the Epilepsy Foundation published an expert consensus (*Epilepsia* 2005; 46:1423–1425) on actions to minimize risks of visually-provoked (photosensitive) seizures (VPS). Since then, technology, scientific information, and experience have greatly expanded. An international expert panel convened by the Epilepsy Foundation collated literature, information, and opinions regarding VPS. Consensus guidelines are divided into advice for: patients and families, clinicians, designers of video games, architects, and regulatory agencies. No attempt was made to develop a formal systematic review. Patients are advised about symptoms and epilepsy syndromes that relate to VPS. Commonly used medications and useful behavioral modifications are reviewed. Clinicians are advised on an approach to events that are concerning for VPS, including how to use history and electroencephalography (EEG) to assess whether an event was a seizure (vs another neurologic symptom) and what visual stimuli (light or patterns) provoked it. The utility of magnetic resonance imaging (MRI) to assess for an epileptogenic lesion, routine blood tests, and genetic studies is discussed. Media designers of video games, movies, TV productions, web videos, and artificial or virtual reality images are advised to avoid bright flashing patterns in the 10–20 Hz range, repetitive color flashes, and oscillating or static stripes of ~1–8 cycles per visual degree. Signal analysis or trained human inspectors can identify provocative visual patterns. Architects and designers of public spaces should be aware that some striped patterns can provoke seizures. Government and regulatory agencies require screening of potentially provocative media in some nations. VPS are both an individual and public health problem. The Epilepsy Foundation

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For affiliations refer to page 13.

encourages further research and efforts to minimize risks of seizures provoked by visual stimuli.

KEYWORDS

epilepsy, guidelines, pattern-sensitive seizures, photoparoxysmal response, photosensitive seizures, reflex epilepsy

1 | INTRODUCTION

The Epilepsy Foundation convened expert panels to consider visual stimuli that can provoke seizures in susceptible individuals. A review[1] and consensus[2] were published in 2005 and updated with a second review[3] and a compendium of questions and answers.[4] The current article completes the series with an updated expert consensus on how to prevent and treat visually-provoked (light-sensitive, photosensitive) seizures (VPS). In the 20 years since the initial consensus, considerable scientific knowledge about provocative stimuli and mechanisms has accumulated. Genetics and imaging have greatly advanced. Hundreds of papers and studies have been published on clinical and electroencephalography (EEG) aspects of VPS. Over a dozen new anti-seizure medications (ASMs) have come to market. New technologies have emerged, such as visual stimuli on the internet, smart phones, portable high-resolution video games, virtual and augmented reality, and larger and brighter TV and computer monitors, including increasing screen times for users

What advice is necessary, given this updated knowledge base? Suggestions for patients might be phrased differently from those for medical professionals or others. This article is divided into sections providing advice to prevent VPS for patients and families, clinicians, game and image designers, architects, and government agencies. Our assumption is that many readers will jump to the section most relevant to them, necessitating a certain amount of repetition and change in level of medical sophistication for each section.

Key points

- A minority of people with epilepsy will have visually-provoked seizures (VPS) triggered by flashing lights, colors, or certain patterns.
- Risks can be minimized by avoiding bright flashing lights (especially at 10–20/s), covering one eye, wearing dark glasses, and staying far back from screens.
- Clinicians should categorize the epilepsy syndrome, perform electroencephalography (EEG) with photic stimulation, image the brain, consider genetic testing or medications, and give advice.
- Games and media should avoid light or color flashes ≥20 candella/m^2 or oscillating patterns at 3–60 Hz, when at more than 25% of the visual field and lasting more than 0.5 s.
- Architects should avoid repetitive stripes, stripes with large color separations, accounting for shadows and the effects of tiles and markings on stairs.

2 | METHODS

This document reflected expert consensus, not a systematic review, for which there would have been insufficient Type A evidence on many of the article's areas of advice. Therefore, we gathered an international group of experts on light-provoked seizures and convened multiple web-based meetings. The group also included a consumer with a child who has epilepsy and support from two staff members from the Epilepsy Foundation. Issues were discussed and advice on them brought to majority and usually unanimous consensus. Section leaders then drafted these into a document, which received multiple edits by the full authorship body. The final document was created by the first and senior authors.

3 | ADVICE FOR PATIENTS AND FAMILIES

3.1 | Definition

Patients are considered visually sensitive if they have either a history of VPS or if they are found to have a photoparoxysmal response (PPR) while undergoing a brain-wave recording, also called an electroencephalogram. A PPR is abnormal brain activity (called epileptiform discharges) induced by exposure to flashing lights, but does not in and of itself indicate epilepsy in the absence of clinical

episodes. VPS are provoked seizures that occur only when the visual stimulus is present, and differ from spontaneous seizures, which occur without clear provoking factors.

3.2 | Prevalence

A PPR is only a risk factor for seizures. If people with VPS are thoroughly tested in an EEG lab, ~90% will show a PPR.[5] The converse is not true, such that only about two-thirds of PPR-positive individuals referred for EEG had VPS.[6] A hospital-based survey of patients who showed a PPR while undergoing EEG noted that 26.4% of 652 cases had only VPS, whereas 63.0% had both spontaneous seizures and VPS. A small percentage (5.8%) of people in this study with a PPR did not have any discernible clinical seizures,[7] but it was suggested that their risk for seizures might be elevated. Although it is difficult to ascertain the number of putatively asymptomatic people without epilepsy who are at risk for VPS (since they rarely undergo an EEG), estimates suggest that somewhere between 0.3% and 8% of people have a PPR. Depending upon the type of epilepsy, young people with VPS often outgrow the condition. In addition, the visual stimuli that trigger epileptic seizures may trigger non-epileptic seizures in individuals without epilepsy.[8]

When visually sensitive individuals are exposed to a strong visual stimulus, they may experience discomforting symptoms (Table 1), as well as seizures.[9] Early recognition of subtle seizures can help to prevent serious convulsive seizures and associated traumatic injuries.

Be aware that many of these symptoms are experienced by people who do not have visual sensitivity but have symptoms of another condition. For example, low blood pressure can lead to dizziness, transient loss of vision, and flashing lights, and migraine headaches also often present with light aversion.[10–12] If these symptoms occur repeatedly and without an identified cause, then your medical team might consider performing EEG with intermittent photic stimulation to evaluate for a PPR, especially for children or adolescents.

TABLE 1 Symptoms that may suggest seizures.

High probability

1. **Abnormal muscle movements or convulsions**: With sustained muscle stiffness in a part or all of the body, tonic seizures may be considered. Repeated bouts of muscle tensing alternating with relaxation (often appearing like "shaking") may underlie tonic or tonic–clonic seizures.
2. **Muscle jerks**: Sudden, brief body movements, such as arm, hand, or leg flicking, may be a symptom of myoclonic seizures. If these affect the arms, they can cause dropping or flinging objects. If the legs are affected, myoclonus or seizures can cause a sudden loss of balance or a fall.

Low or moderate probability in adults

3. **Blinking**: Rapid, uncontrollable blinking may indicate a seizure known as eyelid myoclonia. Blinking also occurs during some absence seizures.
4. **Tics** (specifically, waving a hand in front of the eyes): Patients with a specific type of VPS called Sunflower syndrome can be misdiagnosed with tics. These individuals feel drawn toward bright lights, particularly the sun, and compelled to wave their hand in front of their eyes or roll their eyes slowly. Other tics may also be confused with seizures.
5. **Impairment of consciousness**: A transient loss of memory or reports of unresponsiveness from bystanders may indicate impaired consciousness. This could indicate focal consciousness impaired seizures, or absence seizures.
6. **Transient loss or alteration of vision**: A temporary loss of vision in part or all of the visual field, which may appear hazy, white, or black, may occur as a symptom of focal consciousness preserved seizures. A transient flash of light in part of the visual field, which may change color or move, may occur as a symptom of focal seizures with preserved consciousness, but also from migraines or transient ischemic attacks.
7. **Dizziness**: A non-rotational sense of lightheadedness may occur as a symptom of very brief loss of consciousness.
8. **Headache**: Head pain rarely may be a symptom of a seizure but more commonly of its aftermath.
9. **Light aversion**: Visual sensitivity (or photophobia) may lead to an aversion to bright light or bright environments.

3.3 | Epilepsy syndromes with an elevated risk of VPS

The syndromes below should generate special concern for protective measures, as discussed in a subsequent section.

1. **Juvenile Myoclonic Epilepsy**[13]: This form of epilepsy, characterized by myoclonic and generalized tonic–clonic seizures and, commonly, absence seizures, accounts for 5% to 10% of epilepsy cases. It typically occurs between the ages of 12 and 18 and is more common in female patients. Most patients experience myoclonic seizures upon awakening. Intermittent photic stimulation (IPS) during EEG shows a photosensitive response in 8%–41% (unweighted mean of 25%) of 17 studies, and 15% of patients experience myoclonic or generalized tonic–clonic seizures triggered by flashing lights or video games. A study from Portugal in 2018 showed 15% VPS in therapy-resistant and 27% in non-resistant patients.[14]
2. **Juvenile Absence Epilepsy**[15]: This presents with absence seizures, and this syndrome accounts for 0.2% to 2.4% of epilepsy cases, with generalized tonic–clonic and myoclonic seizures also observed. It typically occurs between the ages of 7 and 17, with 7.5% of patients

showing visual sensitivity during photic stimulation on EEG testing.

3. **Dravet Syndrome**[16]: This is a rare disorder that develops within the first year of life, characterized by febrile or afebrile focal (usually unilateral) or generalized clonic seizures, which are often over 10 min in duration. Dravet syndrome typically has a refractory course. Other seizure types, such as myoclonic and atypical absence seizures, may appear between the ages of 1 and 4 years. VPS, including pattern-induced seizures, occur in 55% of cases.
4. **Progressive Myoclonus Epilepsy**[17]: This rare group of disorders is characterized by myoclonus, epilepsy, and intellectual regression, comprising various epileptic syndromes with diverse symptoms and clinical courses. Myoclonic seizures and generalized tonic–clonic seizures may be induced by visual stimulation.

3.4 | How can a person determine visual sensitivity?

If a person notices unusual or unpleasant symptoms in response to lights, colors, or specific visual patterns, they should discuss these with their medical team to determine whether further testing is indicated. In many instances, people can train themselves to notice their sensitivity to flickering sunlight on water or through trees, striped patterns, or provocative TV screens, as exemplified in the case of a computer specialist.[18] EEG can investigate whether a potentially provocative stimulation induces abnormal brain waves, called epileptiform discharges. During many routine EEG studies, IPS is included because flashing lights are one of the most common triggers for induced seizures. During IPS, patients face a strobe light that flashes at increasing frequencies. Patients will be asked to open and close their eyes. Longer EEG studies with video monitoring, typically while a patient is admitted to a hospital, can record EEG during maneuvers such as playing video games, watching TV, or looking at visually provocative patterns, in order to assess for visual sensitivity.

3.5 | What behavioral modifications reduce the risk of VPS?

Reducing exposure to flashing bright lights, as well as visual stimuli with high contrast, can reduce the risk of VPS. People with VPS or photosensitivity can implement lifestyle changes in order to reduce risk, such as wearing dark sunglasses, covering one eye[19] when exposed to flicker, or optimizing their viewing environment when watching television (TV) or using computers. It is best to avoid situations where flashing lights or specific triggers are likely to occur. In the United States, TV programs, films, video games, and amusement parks typically display warnings if the media contains flashing or strobe lights. People with other types of VPS, such as pattern sensitivity, should be aware of their specific triggers (e.g., checkerboards, stripes)[20,21] because warnings about these potential triggers are rare. Some stripe patterns able to provoke seizures are on the stair tread of escalators, venetian blinds, and with architectural features.

Sunglasses, special filtered lenses, such as Zeiss Z1 blue lenses[22] and precision-tinted lenses,[23] may reduce the risk of VPS. It is important to verify the benefit of self-chosen lenses with repeat photic stimulation, since there are individual differences in the protective effect of colored lenses. Reducing brightness and contrast changes on screens can further mitigate the risk of VPS. People with photosensitivity should avoid screens when fatigued, sleep-deprived, or ill. Smaller TV or computer screens are generally less risky than larger ones, because they do not fill up the entire field of vision; because of this, smartphones seem to cause fewer issues than larger screens. However, "selfies" can rarely provoke seizures.[24] Movies in theaters often are below brightness thresholds to provoke seizures but there are exceptions, with anecdotal cases reported on the internet. Online videos can provoke seizures. The literature in medical journals rarely discusses this topic. An innovative study[25] analyzed reviews from the 10 most downloaded apps on the Google Play Store and found at least 109 reviews mentioning provocation of seizures or induction of pre-seizure symptoms. Flashes were the most common source of complaints but color changes, glitches, and bugs also were mentioned. This affected cohort was a tiny percentage of viewers (drawn from >175 million reviews) but still a significant absolute number of people potentially harmed by the applications. Product reviews from 111 individuals also expressed concern over flashing stimuli that might trigger a seizure, even though the persons providing the product reviews had never had a seizure.[25] It is likely that fear of VPS extends to many other stimuli and might benefit from public education on the realistic risks.

3.6 | Specific suggestions for susceptible individuals

People susceptible to VPS may not know that they are sensitive until they have a seizure. In the famous Pokemon

incident in Japan, 685 children had a seizure provoked by red–blue flashes of a rocket launch while watching the cartoon. For three-quarters of these children, this was their first seizure and they were previously unaware of their photosensitivity.[26]

The following are suggestions for individuals with photosensitivity. People with photosensitivity may find dark lenses that reduce the intensity of all light, blue lenses that eliminate red color, or polarized lenses to be beneficial. Those who have access to an optometrist with an Intuitive Colorimeter[27] may find precision tints useful. If a flickering image or another visual stimulus provokes abnormal sensations, immediately cover one eye with the palm of the hand; this is better than simply closing the eyes, because the hand blocks light more effectively than the eyelid. If safe, both eyes can be covered.

1. **Watching TV**: Watch TV in well-lit rooms and maintain a distance of more than 2 meters (6.5 feet) from the screen. Liquid crystal display (LCD) or light-emitting diode (LED) TVs may be safer than the older cathode ray tube displays. Organic light-emitting diode (OLED) and quantum light-emitting diode (QLED) TVs have a higher brightness than conventional LED screens. Ultra-high-definition (UHD) TVs are known for their even higher resolution and better picture quality. In combination with the increasing size of the screen, the programs and advertisements shown with flicker designed to attract attention will have greater impact and thus be more likely to provoke seizures in photosensitive patients.
2. **Computer Work**: Use caution with old computer monitors that have a slow raster refresh rate in a range likely to provoke seizures. Most modern monitors refresh the screen above perceptible flicker frequencies. Use a computer in a well-lit room to reduce contrast. Scroll slowly. Use smaller monitors/displays that do not occupy the entire visual field and refrain from large screens.
3. **Playing Video Games** on TVs, Computers, or Handheld Devices: Use devices with higher frame rates in well-lit rooms, and avoid using large displays. Do not intentionally produce flicker, for example, by rapidly blocking the image of the sun or a bright light. Do not play alone or for extended periods. When tired, stop playing.
4. **Car Travel**: When a passenger in a car, avoid looking toward the sun passing through trees or toward regularly spaced lights in tunnels. Dark, blue, or polarized lenses may help. If driving (when safe and allowed) tinted glasses with decreased transmission, ideally screened for safety with intermittent photic stimulation testing during EEG, may be advisable. Avoid lenses that make it hard to perceive orange traffic lights.
5. **Train Travel**: Avoid window-side seats and, if possible, close the curtains to minimize exposure to bright light and flicker caused by moving past trees, telephone poles, bridge supports, and provocative environments.
6. **Outdoor Activities**: Flickering effects are most often caused by sunlight passing through leaves or reflecting from water, snow, or other reflective surfaces. Wear long-brimmed hats and dark lenses. Have a companion when pursuing outdoor activities, particularly any that involve water.
7. **Wear Glasses to Limit Light Exposure:** Dark lenses that reduce the intensity of all light, blue lenses that eliminate red color, or polarized lenses can be beneficial. Individuals who have access to an optometrist with an Intuitive Colorimeter may find precision tints useful.

4 | ADVICE FOR CLINICIANS

Clinicians who are treating patients with seizures should be aware that flashing lights, particularly at frequencies at ~10–20 Hz, and certain patterns, even when static but particularly when oscillating across the lines, can provoke seizures in a minority of people with epilepsy. Because these are potentially avoidable factors, their relevance should be explored and discussed with patients, especially those in whom light sensitivity was confirmed on EEG. The approach to patients with light-induced seizures involves several issues.

4.1 | Was it a seizure?

A diagnosis of epilepsy requires a high risk for recurrent, unprovoked seizures but the International League Against Epilepsy (ILAE) formal definition makes an exception for stimulation-provoked (including visual) seizures, considering these to represent epilepsy.[28] The first task in evaluation of any paroxysmal event is determination of whether it was a seizure vs one of the many imitators of seizures. Flashing lights can provoke migraines, sometimes with an element of lightheadedness or confusion.[29] Nonepileptic seizures can be precipitated by unpleasant stimulation, including flashing lights. Is light producing a startle response or hyperekplexia?[30] Diagnosis is best established with careful attention to precipitating conditions, correlation between seizures and visual provocation, plus EEG to look for epileptiform discharges or a PPR. Often patients do not recognize their own sensitivity, and as with epilepsy

diagnoses in general, family members and caretakers are important sources of clinical history.

4.2 | What type of seizure?

The next task is classification of the type of seizure. Was it an isolated event or part of a pattern? Do VPS coexist with spontaneous seizures? Is the onset focal or generalized? Is it part of a neurological syndrome involving seizures and photosensitivity?

Light-induced seizures are most often generalized but 3% of focal epilepsies show photosensitivity,[31] with the percentage higher in children.[32] Other conditions often presenting with focal VPS include occipital epilepsy[33] and periventricular nodular heterotopia.[34] Several clinical epilepsy syndromes are associated with photosensitivity. The clinician should consider whether the patient has juvenile myoclonic epilepsy, generalized seizures upon awakening, juvenile or childhood absence epilepsy, Lennox–Gastaut syndrome, Dravet syndrome, mitochondrial disorder, or one of the myoclonic epilepsies. A few syndromes specifically link seizures to light or pattern precipitation. Sunflower syndrome[35] is characterized by seizures provoked by waving fingers in front of the eyes when staring at a bright light or staring at a provocative pattern, such as venetian blinds. The syndrome is most common in girls and is not thought to be entirely volitional. Jeavons syndrome[36] presents with a photoparoxysmal EEG response provoked by eye closure, eyelid myoclonia with upward jerking of the lids, and associated absence seizures in 25%–50% of patients. Photomyoclonus comprises contractions of the periorbital and forehead muscles in response to light flashes. This may be a simple reflex with no EEG correlate, especially in seniors and at close distance to the lamp, or it can be linked to EEG epileptiform activity.[37]

4.3 | EEG Evaluation of photosensitivity

The most useful laboratory test is EEG with systematic presentation of light flashes and provocative patterns.[5] The goal is evocation of a PPR to flashes, which Waltz[38] divided into four types. Type 1 is occipital spikes that do not outlast the stimuli. This type is normal, and simply reflects active P100 visual evoked potentials. Type 2 includes slow waves in association with parieto-occipital spikes. Type 3 shows spread of evoked discharges to frontal leads, and type 4 generalized spike-waves. As a practical matter, an abnormal epileptiform response to intermittent photic or pattern stimulation is suggested by EEG spikes or sharp waves that outlast the light flashes, spread widely, invoke slow waves or spike-waves, or an electrographic or clinical seizure. The EEG technician should attempt to halt the light flashes prior to an actual seizure. Clinicians should be aware that a PPR indicates a lowered threshold for seizures but is not, in and of itself, diagnostic of epilepsy, unless there is corresponding clinical evidence.

A European expert group formulated detailed methods for an EEG lab or a clinical trial testing for photosensitivity.[5] These involve first obtaining clinical information about the patient, explaining the procedure, and obtaining consent. Testing with intermittent photic stimulation (IPS) and hyperventilation should be separated by at least 3 min. Record for at least 2.5 min with eyes open and 2.5 min with eyes closed before testing IPS. Use a lamp with intensity of at least 0.70 Joule viewed binocularly at 30 cm in dim room lighting. Test with 5 s trains with eyes open, closed, and just after eye closure. As time allows, test frequencies 1, 2, 8, 10, 15, 18, 20, 25, 40, 50, and 60 Hz. For patients with color or video-game sensitivity, test red color flash at frequencies up to 30 Hz. If possible, record while the patient plays a provocative video game or views a triggering pattern. Note any myoclonus or eyelid myoclonia. Many EEG labs will lack the time to perform all of these maneuvers but they can be tailored to particular needs. Be aware that the recommended IPS testing protocol is not usually included in automated programs in U.S. EEG systems and must be performed manually.

About one-third of patients sensitive to IPS are sensitive also to static patterns, such as stripes, checkerboards, spirals, tablecloths, ceiling tiles, and many others. If the pattern vibrates to-and-fro across the stripes, then most IPS-sensitive patients are sensitive to the moving patterns. Patterns drifting smoothly and continuously in the same direction are not a major risk for provoking seizures, although they may be unpleasant to view.[39] A history of pattern sensitivity is uncommon, perhaps because of unawareness that a pattern is provoking discomfort or a seizure. Colored lenses can reduce sensitivity to some patterns.[23] Pattern sensitivity rarely is tested in EEG laboratories,[40] but it should be if a patient provides a relevant history. Many people with seizures provoked by light flash are also sensitive to patterns, and the converse is even more true, in that isolated pattern sensitivity is rare.[41] A PowerPoint presentation with examples of provocative patterns for testing can be found by contacting Professor Arnold Wilkins at arnold@essex.ac.uk. The patterns are designed to be used with a 14-inch screen at a distance of 2 feet. Viewers should recognize that viewing these patterns can provoke seizures, headache, dizziness, nausea, or other symptoms.

These patterns should not be viewed by individuals with seizures. For maximal safety, viewing can be done with one eye covered (not just closed) and ceased for any provoked symptoms.

4.4 | Other laboratory evaluation of visually-provoked seizures

Routine blood tests, such as complete blood counts and metabolic panels do not have a special role with VPS. Similarly, routine imaging usually is unremarkable in people with light-induced seizures or photoparoxysmal EEG responses, but photosensitivity does not preclude an underlying abnormality.

With rare exceptions, people who have had a seizure should undergo some type of brain imaging, ideally magnetic resonance imaging (MRI), which is useful to rule out occipital brain tumors, tubers, malformations, and other brain structural abnormalities. People with VPS show increased parieto-occipital cortical thickness[42] and abnormal white matter connectivity[43] on research-based analyses. Specialized testing may reveal brain structural abnormalities not visible in routine studies. Diffusion studies measuring fractional anisotropy sometimes identify lateral occipital abnormalities and white matter microstructural changes in patients with PPRs.[43] The ascending reticular activating system and ventromedial thalamus show abnormal diffusion studies in patients with photosensitive juvenile myoclonic epilepsy.[44] Functional MRI (fMRI) demonstrates altered blood oxygen level–dependent (BOLD) responses to light flashes in the basal ganglia and motor cortex.[45] Specialized brain imaging is presently of more use in beginning to understand mechanisms of VPS, rather than for routine diagnosis of such seizures.

Genetic testing has had an increasingly important role in the evaluation and management of all epilepsies because it can end the diagnostic odyssey, guide treatment, inform prognosis, assist with reproductive planning, and determine eligibility for clinical trials.[46,47] Whole exome or genome sequencing is now recommended in all patients with epilepsy of unclear etiology. Common genetic generalized epilepsies often associated with VPS, such as juvenile absence and juvenile myoclonic epilepsy, have a complex genetic basis rather than a monogenic etiology, and genetic testing typically has a low diagnostic yield in these cases. In contrast, VPS associated with developmental and epileptic encephalopathies, including Dravet syndrome or epilepsy syndromes with progressive neurological deterioration, such as the progressive myoclonic epilepsies, are likely to be monogenic. Up to 30%–50% of children with Dravet syndrome from mutations in the *SCN1A* gene express VPS.[48] A few suspected susceptibility genes for VPS have been identified, including *NEDD4-2*, which affects voltage-gated sodium channels.[49] About half of patients with mutations in the $GABA_A$ receptor alpha-1 subunit (*GABRA1*) gene demonstrate a PPR or various types of seizures.[50] The chromodomain helicase DNA-binding protein-2 (*CHD2*) gene is associated with absences with eyelid myoclonia and self-induced seizures.[51,52] Several other susceptibility genes are being investigated.[3] Genetic testing has the highest yield in those with VPS in the setting of a developmental and epileptic encephalopathy, epilepsy syndromes with progressive neurological deterioration, comorbid intellectual disability, autism, or a positive family history of epilepsy.[46] Genetic testing should be considered for all others.[47] In most cases, genetic testing should begin with next-generation sequencing modalities such as exome or genome sequencing, as they have the highest diagnostic yield.[46,47] Patients and their families should receive genetic counseling before and after testing.

4.5 | Therapy

Therapy for VPS is primarily with medication. ASMs may be useful if seizures cannot be eliminated by avoiding provocative stimuli, for example, by not playing certain video games. The age and lifestyle of the patient must be considered, to determine whether avoidance suffices. Advice to patients and families is discussed elsewhere in this article. With mixed light-induced and spontaneous seizures or provocations that cannot be avoided, medication may be indicated. No one ASM is indicated specifically for light-induced seizures. The choice of medicine will depend upon the type of seizure, seizure frequency, presence of epilepsy syndromes, concurrent unprovoked seizure types, and tolerability of side effects for individual patients. ASMs that are mentioned in the literature include valproic acid, lamotrigine, levetiracetam, ethosuximide, lacosamide, clobazam, brivaracetam, fenfluramine, cenobamate, and others (see Table 2).

Seizures that are exclusively VPS can sometimes be treated by avoiding the offending visual trigger, depending on age, lifestyle, and especially severity of visual sensitivity both clinically and as measured by EEG. Where provocations cannot be avoided, people with VPS may require a daily ASM to stop seizures. Medications that can treat VPS include valproate (VPA), levetiracetam (LEV), and benzodiazepines as first-line treatments.[65] Evidence of some

TABLE 2 Medications for visually-provoked seizures.

1. Levetiracetam (LEV) reduces visual sensitivity. In 9 of 12 photosensitive patients (75%), a clear suppression (3 patients) or abolishment (6 patients) of IPS-evoked PPRs was observed at a dose between 750 mg and 1000 mg.[53]
2. Lamotrigine (LTG) has been shown to suppress PPRs[54] and is effective in epilepsy syndromes other than JME.
3. Ethosuximide (ESM) is most effective against absence seizures and it has been recommended for certain types of VPS, but no conclusive, long-term studies have been performed.[55]
4. Cenobamate (CNB) is effective in suppressing photosensitivity.[56]
5. Valproate (VPA) is widely supported by past studies as a first-line treatment for VPS. In controlled studies, 39 of 50 patients reported improvement in PPR and VPS, with higher doses being more effective.[53–58] The effect on PPR tends to grow with longer duration of VPA treatment.[59] A high teratogenic potential severely limits use of VPA for women of child-bearing potential.[60]
6. Clonazepam (CZP) is not a first-line treatment for VPS but it may be added in medication-resistant cases or when anxiety contributes to seizures. Tolerance and dependence can occur with long-term use.
7. Clobazam (CLB) can be effective in managing photosensitive seizures, but side effects including drowsiness, dizziness, and fatigue must be considered. Furthermore, tolerance may develop with long-term use, reducing effectiveness and resulting in recurrence of photosensitivity
8. Brivaracetam (BRV) is a promising newer ASM, similar to levetiracetam. One study observed that after a single dose, the PPR on an EEG was abolished in 78% of patients.[61] Long-term studies of its effects on VPS are in process.
9. Fenfluramine (FFA) has been approved for the treatment of seizures associated with Dravet syndrome and other epilepsy syndromes. Several case series and small studies suggest it can reduce VPS, including pattern-sensitive epilepsy and self-induced seizures. It is being explored as a therapy for Dravet and Sunflower syndromes[62]
10. Zonisamide (ZNS) has broad spectrum effectiveness,[63] and ZNS reduced photic-induced seizures in a feline model of epilepsy[64]

Other medications may be used with individual circumstances.

protection against light-provoked seizures exists for the medications in Table 2. Fewer studies have been done for their effectiveness with other visual stimuli. Other ASMs beyond those listed in Table 2 may be useful in particular circumstances, such as mixed light-provoked and spontaneous seizures.

Future therapies may include non-medical treatments, such as gene therapy,[66] neuromodulation,[67] or others yet unknown. Disruption of networks involved in photosensitive responses[68] may provide opportunities for treatment.

TABLE 3 Advice for clinicians.

1. Secure a diagnosis of seizures.
2. Classify the type of seizure.
3. Look for associated epilepsy syndromes.
4. Perform an EEG with intermittent photic stimulation.
5. Record the EEG during individual provocative stimulation, for example, certain patterns or video games.
6. Image brain to rule out a structural cause of seizures.
7. Perform genetic testing in patients with epilepsy of unclear etiology. Patients with developmental and epileptic encephalopathies, epilepsy syndromes with progressive neurological deterioration, an intellectual disability, autism, or a positive family history may benefit from this testing. Counsel patients and families to avoid provocative factors, when possible.
8. Prescribe antiseizure medicine, where appropriate.
9. Provide education and advice to patients and caregivers.

4.6 | Photosensitivity model

The photosensitivity model evaluates the ability of ASMs or putative medicines to inhibit the EEG PPR in people with light-provoked seizures.[69] The advantage of the model is its noninvasive nature and ability to rapidly test drug efficacy in humans with epilepsy, although suppression of the PPR may not predict efficacy against all types of seizures. The photosensitivity model is applied across a range of drug doses and against placebo controls, with a methodology for testing described by Trenité and Löscher.[70] PPRs are most frequently encountered in generalized epilepsies, but can be seen in focal epilepsy.[71] The photosensitivity model is particularly useful in ASM studies,[72] and more than 35 agents have been assayed. Where EEG labs experienced in the photosensitivity model are available, clinicians may choose to employ the model to predict efficacy of a medication in their photosensitive patients.

4.7 | Education and advice

Clinicians should discuss the risks of VPS with patients and caregivers, including things they can do to minimize these risks. Table 3 summarizes recommendations for clinicians treating patients with VPS.

5 | GUIDE FOR VIDEO AND GAME DESIGNERS

When writing software that creates displays of visual information in games, movies, music videos, web pages, three-dimensional (3D) imagery, or virtual or assisted reality, designers should consider individuals with VPS.

These individuals can develop seizures when a display flickers or shows strongly contrasting colors or stripes. This guide describes the visual stimuli that are best avoided and why.

5.1 | The human visual system

Vision results from the activity of nerves (neurons) that undertake a complex computation. The visual system has been designed by evolution so that few neurons are firing at any one time to conserve energy. The brain uses about 20% of the body's energy.[73] The use of energy is minimized by taking advantage of the similarities between the images the eyes see from one moment to the next.

5.2 | The natural world

Images in the natural world may seem very different one from another, but they have three things in common: (1) There is little flicker; (2) there is hardly any monochromatic light, so color contrast is modest; and (3) there are few regular patterns; the difference in brightness from one point to another generally depends on the distance between the points. The coding used by the neurons in the brain takes advantage of these features and the visual system operates efficiently with scenes from nature.[74]

In the urban environment and on a computer screen the eye sees very un-natural images. Flicker is common and the color can be strongly saturated and close to monochromatic. Striped patterns, rare in nature, are everywhere: in texts, and on grills, grids, floor coverings, and building frontages. As a result, the neurons work harder than they would in nature and the oxygen used by the brain increases.[75] Visual stimulation gives rise to strong rhythmic neural firing[76] and generates seizures when a susceptible individual looks at flickering lights or certain patterns. The visual stimuli that trigger migraine headaches and epilepsy are broadly similar. Both disorders occur as a result of strong neural stimulation, but the stimulation has to be rhythmic to cause seizures, whereas this is not the case for migraine.[39]

5.3 | Flicker

The visual stimuli that cause strong neural firing are usually those that are easiest to see. Flicker of lights is most easily seen by the human eye when it occurs at about

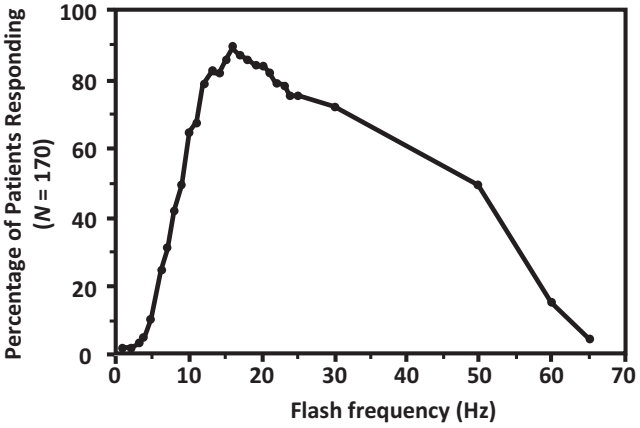

FIGURE 1 Percentage of patients with photosensitive epilepsy at risk of a seizure from flicker shown as a function of the frequency of the flashes (adapted from Harding and Jeavons[77]).

16 flashes per second and this is the frequency that is most likely to cause photophobia or seizures. Patients can be sensitive to flashes from 3 to ~60 per second but the most commonly provocative frequencies are in the range of 10–20 Hz (Figure 1).

The larger the area of the retina receiving flicker, the greater the risk of discomfort or seizures. A flickering light at the center of gaze is a greater risk than if the same light is seen at the periphery of vision. This is because more of the brain is involved in analyzing central vision and the risk of seizures depends on the size of the brain area receiving stimulation.[78]

Risk increases with high luminance and with high contrast between the bright and dark periods or spaces. If the contrast (difference between the peak and the time-averaged illuminance divided by the time-averaged luminance) is less than 5%, the risk is low. Risk increases as contrast increases, reaching a maximum at 30% contrast and above.[78]

A light that keeps a constant illuminance but alternates in color can also be hazardous. Risk depends on the difference in International Commission on Illumination (CIE) 1976 Uniform Chromaticity Scale (UCS) chromaticity between the alternating colors.

The greater the separation of colors on the diagram in Figure 2, the greater the risk. So red–blue alternation in the frequency range of 3–60 Hz is a hazard, whereas, red–orange alternation is much less of a risk.[79]

5.4 | Patterns

About one-third of people with photosensitive epilepsy are at risk not just from flicker but also from steadily illuminated repetitive patterns, such as stripes, particularly if large and of high contrast. A finger at arm's

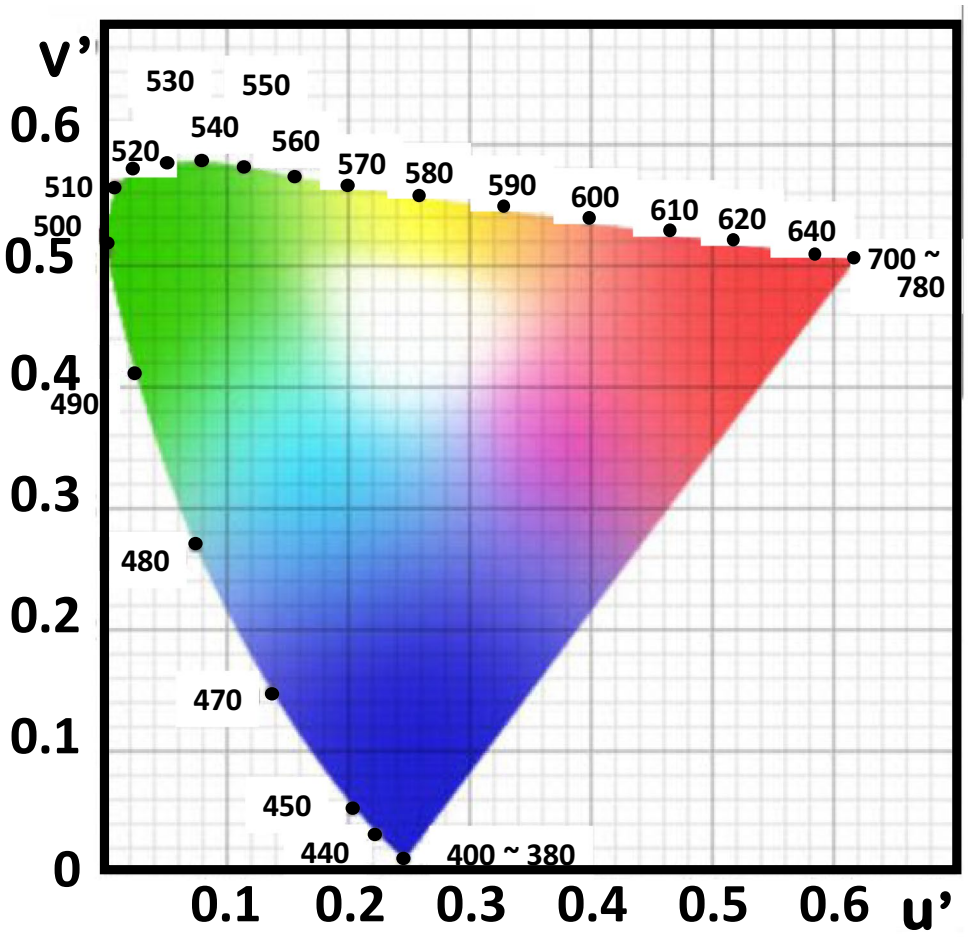

FIGURE 2 CIE UCS 1976 Chromaticity diagram. The axes are ratios calculated on the basis of the energy captured by the three classes of cone photoreceptors at constant luminance. Adapted from https://www.konicaminolta.com/instruments/knowledge/color/part4/08.html.

length covers about one degree subtended at the eye. The patterns that are most likely to cause seizures are stripes that have about three cycles of the pattern in one degree. About 50% of patients are sensitive in the range of 1–8 cycles per degree. The risk increases with pattern size, but if the entire pattern subtends less than 1 degree at the observers eyes it is of little risk.[78] If the stripes are colored, the risk increases with the difference in CIE UCS chromaticity (Figure 2). Pattern-sensitive patients are a special subtype of VPS with more localized occipital epileptiform discharges and symptoms like ocular discomfort, dizziness, and headache while viewing patterns. There are also patients who use patterns to self-induce seizures.[71,80,81]

In the natural world, the only stimuli that are likely to trigger epilepsy are sunlight interrupted by the leaves of trees or reflected from waves on the surface of water. If these sources of flicker are created on a screen it is best to avoid local flicker at frequencies in the range of 3–60 Hz.

5.5 | Light-emitting diodes (LEDs), virtual reality, and 3D

Building lighting and monitor screens increasingly use LEDs, which can be very bright. There are three concerns: the brightness of point sources of light; the nature of the spectrum; and the variation in light output over time. Although it is unclear whether the brightness concentration or spectrum poses increased risks for seizures, the temporal variation in light output is a definite risk at low frequencies at which the flicker is visible. It is not known whether long-term exposure to flicker at higher frequencies is also a risk, although it is known to cause headaches.[82]

Evidence does not support specific increased risks from virtual reality or 3D imagery. Relatively little research exists to support or refute their safety. Provocation by the flicker resulting from left–right switching of active 3D glasses might be problematic.[83] Passive glasses, polarized differently in the left and right, are not likely to contribute to seizure provocation.

5.6 | Technology and testing

Technology can test, assay, and sometimes modify visual stimuli presented by electronic media, in order to reduce the risk that the media may provoke a seizure. Recorded media can be played into a flash-pattern analyzer (http://www.hardingfpa.com/) to display a probability that the media includes characteristics that are a risk. Equipment to provide this analysis can be purchased, rented, or used via an online submission of media. A photosensitive epilepsy analysis tool developed by the University of Maryland (PEAT; https://trace.umd.edu/peat/) can be freely downloaded and used to assay whether animations or video material is likely to cause seizures.[84] Other analytic testing software comes and goes on the web, but such tools may or may not be accurate and reliable. No equipment or software screener can guarantee that a particular visual image or animation will be entirely safe, although screening can reduce the risk of seizure provocation. In the United States and most other countries, currently there is no requirement for broadcast or public media to be screened for a tendency to provoke seizures.

Video games provide special problems for risk screening because a game can be played in countless ways, only some of which might be provocative; for example, by having a game figure jump up and down to intermittently block an image of the sun. Large video game manufacturers employ experienced quality assurance testers to run the game through multiple scenarios. Provocative material may be uncovered by such human testing. The International Game Developers Association (IGDA; https://igda.org/) offers guidelines on how to design seizure-safe video games. Not all behavioral arrests or muscle twitches during video game playing are due to seizures; some are due to fatigue, migraines,[85] or other causes.

Media that are presented on a TV or computer screen can be intercepted and screened by plug-in hardware[86] that detects flashes or patterns in near real-time, in order to reduce brightness for that segment of media. Artificial intelligence deep networks have the ability to transform provocative to harmless stimuli.[87] Such equipment has not experienced wide adoption. Certain social media platforms and smart phones provide software options for users to turn off auto-play or be alerted to potentially provocative animations. Apple allows developers to incorporate a "Dim Flashing Lights" app to enable automated brightness reduction at times of light flashes (https://developer.apple.com/documentation/mediaaccessibility/responding-to-changes-in-the-flashing-lights-setting).

TABLE 4 Advice for media designers.

Suggest to avoid

1. Light flashes with luminance ≥20 candela/m^2 that recur with a frequency in the range of 3–60[a] Hz.
2. Alternate color flashes (particularly red–blue) in the frequency range of 3–60[a] Hz.
3. Bright or colored stripes or zig-zags having 1–8 cycles that subtend 1 degree at the eye (the width of one finger held at arm's length covers 1–8 cycles of the pattern), particularly if they oscillate in the frequency range of 3–60Hz[a].

The above stimuli are particularly likely to provoke seizures if they occupy more than about 25% of the visual field of both eyes for more than about 0.5 s

[a]Maximum risk is from 10 to 20 Hz.

5.7 | Overview for designers

This guide is not intended to limit imagination or creativity. It may assist designers with recognition of potential triggering effects. Once these aspects of design are identified, it would be possible to provide guidance for observers, and give them the option to avoid the triggers. To minimize risks for provoking seizures in photosensitive individuals, consider avoiding the factors in Table 4:

A subset of light-sensitive people with epilepsy have seizures that can be provoked by patterns, even in the absence of light flashes. Oscillating patterns are usually most provocative but static patterns also can be provocative. Periodic patterns are rare in nature; they are common in human construction. Architects are increasingly aware of seizure-provoking aspects of design, such as high-contrast striped patterns, flashing images, and certain colors, such as dark red. The level of awareness and implementation of guidelines may vary across industries. Some architects may have basic knowledge of sensory sensitivities but their formal education does not always emphasize seizure triggers. Awareness is often gained through experience, client feedback, or collaborations with experts in accessibility and neurodiversity. Some safety standards, such as stripes at the edge of each stair may reduce one risk (tripping) while increasing another (seizures).

In the UK, a consortium of organizations has produced a publicly available specification (PAS), including safety recommendations for buildings, although it does not specifically address epilepsy. https://knowledge.bsigroup.com/products/modern-methods-of-construction-for-new-build-residential-properties-specification.

Certain recommendations on the internet pertain to architectural design and seizures https://www.architecture.com/knowledge-and-resources/knowledge-landing-page/

TABLE 5 Minimizing architectural provocations of seizures.

1. Avoid unnecessary repetitive stripes that appear at an angle of 4–60 min of an arc.
2. With unavoidable stripes, keep the luminance difference less than 10% of the average luminance.
3. Minimize color separation in stripes.
4. Attend to stripes caused by shadows.
5. In paving patterns, use stones of different sizes.
6. With tiles, choose a grout to reduce contrast

how-can-architects-design-for-neurological-conditions.[88] These include indirect and natural lighting, furniture, materials, and floor coverings designed to minimize injuries from falls, and avoiding repetitive and contrasting patterns. Some accessibility guidelines, such as those in the Americans with Disabilities Act (ADA) or Universal Design principles, mention visual comfort but do not always explicitly address seizure risks. There is growing interest in designing sensory-friendly environments that minimize visual stress. No universally enforced regulations exist for seizure prevention.

Patterns with sufficient size contrast and spatial frequency to provoke seizures are a common feature of architectural design, increasingly so over the last century.[89,90] The architectural design features in Table 5 can minimize risk for seizures.[89]

6 | ADVICE FOR GOVERNMENT AGENCIES

National safety regulatory agencies tend to be responsive to high-profile incidents. In 1997, a Tokyo TV Pocket Monster cartoon included a 12 Hz red-to-blue-to-red "rocket launch sequence" that was watched by 6–7 million children. This color flash sequence resulted in 685 hospitalizations, about 560 of which were for seizures, and others for migraines, visual distortions, and other symptoms. As a consequence, the Japan National Association of Commercial Broadcasters and the Japan Broadcasting Corporation issued safety guidelines for animation programs. Flashes above 3 Hz, color flashes involving red, and regular patterns involving stripes, spirals, and concentric circles were restricted. After implementation of the guidelines, a national survey found that the number of reported light-provoked seizures was markedly decreased.[7]

The UK also has had incidents leading to regulations. A 1993 commercial included flashing visuals that precipitated 29 complaints to the Independent Television Commission (ITC), including at least three seizures that occurred while watching. Professor Graham Harding introduced the ITC guideline that broadcast media should not include flashes above 3 Hz. A subsequent commercial for the 2012 London Olympics (https://www.reuters.com/article/sports/london-2012-logo-footage-withdrawn-amid-epilepsy-fears-idUSHO638735/) induced seizures in some viewers when colored lights shimmered off pool water during diving. The commercial had contravened the broadcast safety guidelines and was withdrawn. In 2019, the Epilepsy Foundation's Twitter (now X) site was the target of a malicious web attack posting flashing video material on some of their web forums (https://www.cnn.com/2019/12/17/tech/epilepsy-strobe-twitter-attack-trnd).

Jordan and Vanderheiden[84] provided a thorough review and comparison of five sets of guidelines for seizure prevention in broadcast and display screen media, from the UK, Japan, International Telecommunications Union of the United Nations, and the International Organization for Standardization and the World Wide Web Consortium (W3C). Tabulation of flash frequencies, luminance, and area of the visual field covered indicate the following safety ranges: frequency <3 or 5 flashes per second; brightness differential of the light-to-dark regions during flashing below 20 candelas per square meters; avoidance of flashes to and from a saturated red; and area less than 0.006 steradians or about 25% of the visual field. The UK guidelines also address provocative patterns, allowing unidirectional smooth movements but prohibiting oscillating patterns of certain sizes and frequencies.

Eler and Aljedaani[25] compared guidelines from multiple web-related sites, including the Web Content Accessibility Guidelines,[91] British Broadcasting Corporation's Mobile Accessory Guidelines,[92] and Mozilla Accessibility Guidelines.[93] The former two emphasize high risk from flashes above 3 per second and allowing disabling of motion animation. The Mozilla guidelines also incorporate discussions of color changes, patterns, moving backgrounds, and avoiding auto-play.

One role of governments, media, game makers, builders, and other agencies can be to provide warnings of potentially provocative stimuli. An example of a warning can be found at www.epilepsie.nl/over-epilepsie/waarschuwing-icoon-flitsen-en-patronen/ (Dutch). These can be helpful but warnings may not influence those who have not had seizures, or the warnings may be ignored.

The Eplepsy Foundation encourages all nations to develop, adopt, or adapt guidelines for broadcast media, video monitors, movies, internet visuals, video games, building and public architecture, and other visual experiences in order to minimize the risk of provoking VPS. The goal is not to reduce creativity or interest in visual materials but to keep them as safe as possible for people with epilepsy. In many cases these guidelines also would likely benefit other populations, such as those with migraines or

balance disorders. In the United States, currently provocative material often is modified after a health-endangering event or a lawsuit; prevention would be better.

AUTHOR CONTRIBUTIONS

Robert S. Fisher: Wrote first and last draft, drafted section on definitions and advice for government agencies, and is co-corresponding author. Arnold Wilkins: Led advice to designers section, contributed to section on advice for architects, provided figures, and edited manuscript. Liu Lin Thio: Contributed to advice for clinicians section and edited manuscript. Jayant Acharya: Contributed to advice for clinicians section and edited manuscript. Modhi Alkhaldi: Edited manuscript. Fiona Mitchell Baumer: Contributed to advice for clinicians section and advice to patients and families section and edited manuscript. Roy G. Beran: Edited manuscript. Dana Craiu: Contributed to recommendations for architects section and edited manuscript. Jaqueline French: Contributed to advice to patients and families section and edited manuscript. Nasir Mirza: Edited manuscript. Pasquale Parisi: Contributed to recommendations for advice to clinicians and architects section, led discussion of headache and visual sensitivity, and edited manuscript. Jessica Solodar: Contributed to advice for patients and families section, provided patient perspective, and edited manuscript. Jerzy P. Szaflarski: Contributed to advice for clinicians section and edited manuscript. Benjamin Tolchin: contributed to advice to clinicians section and edited manuscript. Dorothee Kasteleijn-Nolst Trenite: planned and led paper strategy, co-wrote final draft, led section on advice for architects, and finalized the section on the photosensitivity model and is co-corresponding/senior author.

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ACKNOWLEDGMENTS

Fisher acknowledgements: The Maslah Saul MD Chair. R.S.F. received funding from the National Institutes of Health (NINDS; 1RO1NS137650), NaviFUS, and support from the James and Carrie Anderson, the Steve Chen, and the Pilliod Funds for epilepsy research. Baumer acknowledgements: Research funding from NINDS K23NS116110, the Doris Duke Charitable Foundation, the Rita Allen Foundation, the Wu Tsai Neuroscience Institute, and the O'Farrel-Principe family. Szaflarski acknowledgements: Funding: NIH, NSF (National Science Foundation), DoD (Department of Defense), Shor Foundation for Epilepsy Research, UCB Biosciences, NeuroPace Inc., SAGE Therapeutics Inc., Serina Therapeutics Inc., LivaNova Inc., Greenwich Biosciences Inc., Biogen Inc., Eisai Inc., and state of Alabama. Kasteleijn-Nolst Trenite acknowledgements: The European Union for a Marie Curie Excellence Chair position in Sapienza University, Rome, Italy (MEXC-CT-2005-24224: Visual Sensitivity) and for continued working with the Roman and Italian (child)-neurologists on this subject.

CONFLICT OF INTEREST STATEMENT

Robert Fisher: No disclosures relevant to this paper but stock options in Avails Medical, Eysz, Irody/CareTuner, Smart Monitor, and Zeto. **Liu Lin Thio**: Editorial board for *Neurology* and a consultant for the Epilepsy Study Consortium, through which is a consultant for Anavex Life Sciences Corp, Eisai, GW Pharmaceuticals, the LouLou Foundation, Marinus Pharmaceuticals, Ovid Therapeutics, SK Biopharmaceuticals, Stoke Therapeutics, Takeda Pharmaceuticals, and Zogenix. **Jaqueline French**: Receives salary support from the Epilepsy Foundation and from Epilepsy Study Consortium for consulting work and/or attending scientific advisory boards for Acadia Pharmaceuticals, Access Industries, Acuta Capital Partners, AFASCI Inc., Agrithera, Inc., Alterity Therapeutics Limited, Angelini Pharma S.p.A, Autifony Therapeutics Limited, Axonis Therapeutics, Bain Capital, Beacon Biosignals, Inc., Biogen, Biohaven Pharmaceuticals, Bloom Science Inc., Bright Minds Biosciences, Inc., Capsida Biotherapeutics, Cerebral Therapeutics, Cerecin Inc., Cerevel, Ceribell, Cognizance Biomarkers, Cowen and Company, LLC, Crossject, EcoR1

Capital, EG 427, Eisai, Encoded Therapeutics, Engrail, EpiMinder, Epitel Inc., Grin Therapeutics, Harmony/Epygenix, Ionis Pharmaceuticals, iQure Pharma Inc., IQVIA RDS Inc., Janssen Pharmaceutica, Jazz Pharmaceuticals, Leal Therapeutics Inc., LivaNova, London Research & Pharmaceuticals, Longboard Pharmaceuticals, Maplight Therapeutics, Marinus, Medscape/Web MD, Modulight.bio, Mosaica Therapeutics, Neumirna Therapeutics, Neurelis, Neurocrine, Neurona Therapeutics, NeuroPace, Inc., NeuroPro Therapeutics, Neuroventis, Neurvati, Noema Pharma, Ono Pharmaceutical Co., Otsuka Pharmaceutical Development, Ovid Therapeutics Inc., Praxis, PureTech LTY Inc., Rapport Therapeutics, Inc., Receptor Holdings Inc., Rivervest Venture Partners, Sage Therapeutics, Inc., SK Life Sciences, Stoke, Stream Neuroscience, Supernus, Takeda, Taysha Gene Therapies, UCB Inc., uniQure, Ventus Therapeutics, Vida Ventures Management, and Xenon. She has also received research support from the Epilepsy Study Consortium (funded by Eisai and UCB,) Epilepsy Study Consortium/Epilepsy Foundation (Funded by UCB), GW/FACES / One8Foundation, NINDS, and Praxis. She is on the editorial boards of *Lancet Neurology* and *Neurology Today*. She is Medical Director for the Epilepsy Foundation. She is the President and on the Board of Directors for the Epilepsy Study Consortium, Inc. She has received travel/meal reimbursement related to research, advisory meetings, or presentation of results at scientific meetings from the Epilepsy Study Consortium, the Epilepsy Foundation, Biohaven Pharmaceuticals, Cerebral Therapeutics, Ceribell, Cowen and Company, LLC, Harmony Biosciences, LivaNova, Longboard, Maplight Therapeutics, Neumirn a Therapeutics, Neurocrine, NeuroPace Inc., Neurvati, Praxis, Rapport, Supernus, Takeda, Ventus, and Xenon. **Jerzy P. Szaflarski**: Consulting/Advisory Boards: PureTech Health, Biopharmaceutical Research Company, LivaNova Inc., UCB Pharma, AdCel Pharma, iFovea Inc.; Editor-in-Chief, *Epilepsy & Behavior Reports* (paid). **Benjamin Tolchin**: The institution of Dr. Tolchin receives research funding from the C.G. Swebilius Foundation. **Dorothee Kasteleijn-Nolst Trenite**: Nothing relevant to this paper, but consultant in the past 3years for Jazz Pharmaceuticals, Praxis Precision Medicines, NeuroPro therapeutics, and Axonis Therapeutics. She receives royalties from Wolters Kluwer Publishers (UptoDate). The remaining authors have nothing to disclose.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

ETHICS STATEMENT

We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

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How to cite this article: Fisher RS, Wilkins A, Takahashi Y, Thio LL, Acharya J, Alkhaldi M, et al. Visually-provoked seizures: Consensus of the Epilepsy Foundation Working Group. Epilepsia. 2025;00:1–17. https://doi.org/10.1111/epi.18702