Journal of the Neurological Sciences 428 (2021) 117611

Contents lists available at ScienceDirect

Journal of the Neurological Sciences

journal homepage: www.elsevier.com/locate/jns

Review Article

Commercially available seizure detection devices: A systematic review

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ARTICLE INFO

Keywords:
Epilepsy
Seizure detection device

ABSTRACT

Importance: Epilepsy can be associated with significant morbidity and mortality. Seizure detection devices could be invaluable tools for both people with epilepsy, their caregivers, and clinicians as they could alert caretakers about seizures, reduce the risk of sudden unexpected death in epilepsy, and provide objective and more reliable seizure tracking to guide treatment decisions or monitor outcomes in clinical trials.
Objective: To synthesize the characteristics of commercial seizure detection tools/devices currently available.
Methods: We performed a systematic search utilizing a diverse set of resources to identify commercially available seizure detection products for consumer use. Performance data was obtained through a systematic review on commercially available products.
Observations: We identified 23 products marketed for seizure detection/alerting. Devices utilize a variety of mechanisms to detect seizures, including movement detectors, autonomic change detectors, electroencephalogram (EEG) based detectors, and other mechanisms (audio). The optimal device for a person with epilepsy depends on a variety of factors including the main purpose of the device, their age, seizure type and personal preferences. Only 8 devices have published peer-reviewed performance data and the majority for tonic-clonic seizures. An informed conversation between the clinician and the patient can help guide if a seizure detection device is appropriate.
Conclusions and relevance: Seizure detection devices have a potential to reduce morbidity and mortality for certain people with epilepsy. Clinicians should be familiar with the characteristics of commercially available devices to best counsel their patients on whether a seizure detection device may be beneficial and what the optimal devices may be.

1. Introduction

Seizure detection devices could be invaluable tools for both people with epilepsy (PWE), their caregivers, and clinicians. For people with epilepsy, having a device that could alert caretakers to seizures would help relieve anxiety from the helplessness that seizures can cause. It could also potentially reduce the risk of sudden unexpected death in epilepsy (SUDEP). SUDEP affects 1 in 4500 children and 1 in 1000 adults per year [1] and the risk is increased up to 34-fold if someone shares a household but not a bedroom or up to 82-fold if they live alone compared to PWE sharing a bedroom [2]. Most cases of SUDEP occur during sleep and terminal seizures are often unwitnessed. It is thought that if a caregiver is able to help immediately after a seizure they may interrupt the cascade of events that could have led to death or may be able to provide timely first aid [3,4]. Nocturnal supervision and the use of a nocturnal listening device could reduce SUDEP risk [1,5], however there is currently insufficient evidence that devices can prevent SUDEP [6], as these studies are difficult to perform. Alerting caretakers to seizures can also reduce morbidity and mortality from injuries such as falls or burns or allow the prompt administration of rescue mediations to prevent status epilepticus or seizure clusters [7]. However, utilizing these devices for safety requires a caregiver to be available and able to provide timely aid [8]. Most adults with epilepsy are single and social isolation is common [9]. In addition, it is possible that immediate aid is insufficient [10] and SUDEP has been reported in the absence of seizures [11].

For clinicians, seizure detection devices can be an important tool because self-reporting of seizures is unreliable [12–14], with under-reporting of seizures, particularly in those with cognitive deficits from their epilepsy or anti-seizure medications or are amnestic to their seizures. Seizure detection devices provide objective tracking of seizure frequency, allowing the clinician to assess response to therapy and appropriately adjust medications. Accurate quantification of seizures would also be beneficial in clinical drug trials, which commonly use a

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https://doi.org/10.1016/j.jns.2021.117611
Received 21 May 2021; Received in revised form 2 August 2021; Accepted 3 August 2021
Available online 6 August 2021

primary outcome of seizure frequency reduction.

The goal of this review is to provide a comprehensive and unbiased list of commercially available seizure detection devices and their characteristics. There are multiple types of seizure detection devices with different sensors and detection mechanisms. The optimal seizure detection device for a particular person with epilepsy will depend on the main purpose of the device, personal preferences, age, and seizure type. Device development and new biosensors are advancing at a rapid rate and performance will continue to improve. The future of these devices will likely incorporate seizure prediction/forecasting along with detection.

2. Methods

We performed two systematic searches, one to identify commercially available seizure detection devices and a second to identify peer-review published performance data on commercially available seizure detection devices. To identify seizure detection devices we utilized a diverse set of resources including PubMed, clinicaltrials.gov, abstracts from the 2nd International Congress on Mobile Devices and Seizure Detection in Epilepsy 2019, and websites of epilepsy advocacy organizations. We searched the PubMed database for English language full text articles published between Jan 1 2015 and Mar 31, 2021 using the following search terms "((seizure[Title/Abstract] OR convulsion[Title/Abstract]) AND (detection[Title/Abstract] OR detector[Title/Abstract] OR detecting[Title/Abstract])) AND (device[Title/Abstract] OR sensor[Title/Abstract] OR biosensor[Title/Abstract] OR monitor[Title/Abstract] OR system[Title/Abstract])". We reviewed abstracts and further article text if needed to determine if a commercially available seizure detection device was utilized. From this PubMed search, we identified 11 review articles on seizure detection device performance [15–24] and references from these reviews were examined as well. We searched ClinicalTrials.gov database for condition epilepsy and search term seizure detection. We reviewed the community websites sudep.org, dannydid.org, epilepsy.org.uk, and epilepsy.com. Specifically, for epilepsy.com we additional reviewed the shark tank 2013–2020 winners (https://www.epilepsy.com/make-difference/research-and-new-therapies/innovation/epilepsy-therapy-project/shark-tank), epilepsy device-apedia database (https://www.epilepsy.com/deviceapedia-listing-page), and epilepsy pipeline database (https://www.epilepsy.com/pipeline-listing-page). Once a commercially available device was identified, the company website was utilized to obtain information about the device. If information was not readily available, the company was contacted to obtain the necessary information. A device was excluded if it was not marketed for seizure detection or if there was no avenue for a consumer to purchase the device in US or Europe. To identify peer reviewed studies on performance data of commercially available devices, we used the PRISMA guidelines [25] and screened 728 publications obtained from PubMed and the review references as detailed above (Fig. 1). Inclusion and exclusion criteria are detailed in Figs. 1 and 18 full text articles were identified and further reviewed. For devices with greater than one article, the article(s) with the highest phase of study design [26] were included. 9 articles with a lower phase of study design were excluded. This left 9 studies which were used to synthesize performance data. Data variables that were collected from each article included sensitivity for each seizure type and false alarm rate. Confidence intervals were obtained if provided. Due to the variability in reporting for false alarm rate, the number of alarms and hours of recording time were also collected and the false alarm was calculated as alarms per 24 hours.

3. Observations

3.1. Detection mechanisms

There are multiple types of seizure detection devices ranging from movement detectors (accelerometers, gyroscope, magnetometer, piezoelectric bed sensors, surface electromyography (EMG), eye tracking, video monitors), autonomic change detectors (heart rate/pulse, electrodermal response, temperature, respiration, oxygen saturation, blood pressure), and EEG based detectors (surface and implantable intracranial systems), as well as other mechanisms (audio, near infrared spectroscopy).

3.2. Commercially available devices

There are currently 23 options for commercially available devices/tools in the US or Europe (Table 1 and Table 2), however only 3 of these devices have regulatory approval (Embrace, SPEAC, Pulse Companion) and only 8 of these devices have peer reviewed published data on performance (Fig. 1). The optimal device for a particular person with epilepsy depends on the main purpose of the device, personal preferences, age, and seizure type. The options are divided into two broad categories: whether they are designed for in-home detection (Table 1) or for ambulatory detection (both in the home and outside the home, Table 2). In-home detection devices typically utilize a mechanism that is not portable (e.g., video sensor or bed movement sensor) or have a non-

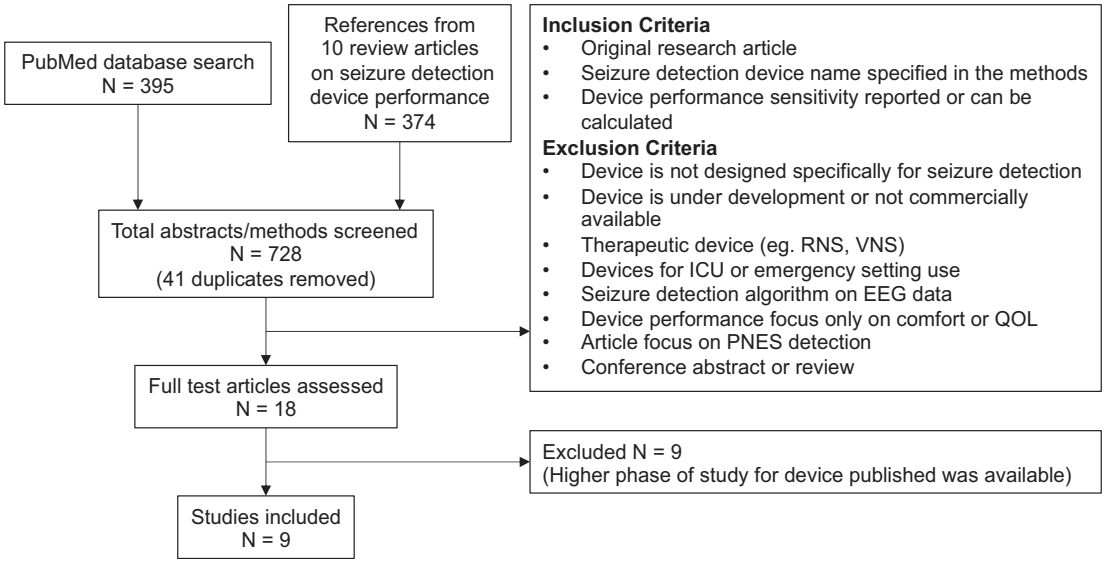

Fig. 1. Flowchart of study selection process.

Table 1
Commercially available devices for in-home detection, sorted by mechanism.

Name	Mechanism	Detector location	Targeted seizure type	Country Available	Performance Data	Regulatory Approval	Targeted Age	Alerting	Tracking	Cost
Epi Night Nurse	Video monitoring service	Bedside	Clinical seizures	Inter-national	None	No	All ages	Alerts locally and to phone	No	Optional set up fee and recurring fee $395–$495/mo
Pulse companion	Heart rate	Armband	Ictal tachycardia or bradycardia	Europe and Australia	None	Yes - MHRK of UK	All ages	Alerts locally and to phone	No	$710*
Brio epilepsy monitor	Heart rate	Wrist	Ictal tachycardia or bradycardia	UK	None	No	Age 2 and above	Alerts locally	Yes	$708*
PulseGuard Mark II	Heart rate	Arm or ankle	Ictal tachycardia or bradycardia	Inter-national	None	No	6 months and above	Alerts locally	Yes	$511* + recurring fee $43*/mo
Epi-Care free	Motion	Wrist	Tonic clonic	Europe	Good performance - sensitivity 90% and FAR 0.1/day (phase 4) [29]	Yes – CE mark	Age 10 and above	Alerts locally and to phone	Yes	Starting at $1985*
Medpage MP5	Bed movement and audio	Bed	Tonic clonic	UK	Variable performance - sensitivity 62.5% in one study (phase 2) [30] and 11.1% in another (phase 3) [31]	No	Weight > 25 kg	Alerts locally	No	Starting at $289*
SensAlert 200	Bed movement	Bed	Tonic clonic	UK	None	No	Weight > 18 kg	Alerts locally	No	$955*
Companion mini, Companion solution, Guardian	Bed move-ment +/− sound or vomit/urination	Bed	Tonic clonic	Europe and Australia	None	No	All ages (but less reliable for smaller children)	Alerts locally	No	$328* to $965*
Nelli home	Video motion	Bedside	Motor seizures	Europe	None	No	All ages	No	Yes	$245* per day for 14–30 days, requires MD order
Sami-3	Video motion	Bedside	Tonic clonic	US and Australia	None	No	All ages	Alerts locally	Yes	$399
Epi-Watcher	Bed movement	Bed	Tonic clonic	Inter-national	None	No	All ages (but less reliable for smaller child-ren)	Alerts locally	Yes	$1190*
Epi-care 3000	Bed movement	Bed	Tonic clonic	Europe	None	No	6 months or older	Alerts locally and to phone	Yes	$1504*
Emfit MM Movement Monitor	Bed movement	Bed	Tonic clonic	US, Canada, Mexico	Variable performance - sensitivity 21% for various seizure types and FAR 0.03/night in natural environment study (phase 4) [32], while other small studies showed sensitivity ranging from 75 to 89% (phase 2–3) [31,37,38]	No	All ages (but less reliable under 35 lbs)	Alerts locally	No	$594
Nightwatch	Multi-modal – motion and heart rate	Armband	Tonic clonic, tonic, hypermotor, clustered myoclonic seizures	Europe	Good performance - sensitivity 86% and FAR 0.25/night (phase 4) [32]	No	Age 4 and above	Alerts locally and can alert to phone	Yes	$1822*

Legend: FAR = false alarm rate.
* Conversion from original currency to dollars.

portable control unit with a limited range from the sensor. These devices would be ideal for nocturnal seizures or if one of the primary goals is to alert a family member/caretaker for nocturnal seizures to reduce the risk of SUDEP. In-home detection devices can be used for a wider age range, and some even for infants (e.g., video sensors, bed movements sensors if the infant is above a certain weight, or the PulseGuard Mark II heart rate detector sensor which can be used for 6 months and older). Ambulatory detection devices require a compatible smart phone which serves as the

Table 2
Commercially available devices for ambulatory detection, sorted by mechanism.

Name	Mechanism	Detector location	Targeted seizure type	Country Available	Performance Data	Regulatory Approval	Targeted Age	Alerting	Tracking	Cost
Epihunter	EEG	Scalp	Absence seizures	Europe	No	No	Age 4 and above	Alerts locally	Yes	$48* - $55*/mo
Seizario	Motion	Waist - phone in pocket or on belt	Tonic clonic or seizures causing falls	International	No	No	Older child or adult	Alerts to phone and can send GPS location	Yes	Free, but requires compatible android phone
EpDetect	Motion	Waist - phone in pocket or on belt	Tonic clonic	International	No	No	Older child or adult	Alerts to phone and can send GPS location	Yes	Free, but requires a smart phone
SeizAlarm	Motion +/− heart rate	Wrist or Waist	Tonic clonic	International	No	No	Older child or adult	Alerts to phone and can send GPS location	Yes	Recurring fee $14.99/ mo or $149.99/ year, requires a compatible iPhone +/− apple watch
Seizure Sync	Motion	Wrist	Tonic clonic	International	No	No	Older child or adult	Alerts to phone and can send GPS location	Yes	Free, but requires a pebble smart watch & smart phone
Smart Watch Inspyre	Motion	Wrist	Tonic clonic	International	Variable performance - sensitivity 92.3%, FAR unclear in one study (phase 3) [33] and sensitivity 31% and FAR unclear in another study (phase 3) [37]	No	Age 3 and above	Alerts to phone and can send GPS location	Yes	$20 + recurring fees $14.95 - $49.95/ mo, requires compatible smart watch & smart phone
Epi-care mobile	Motion	Wrist	Tonic clonic	Europe	Good performance – 90% sensitivity and FAR 0.1/day (phase 4) [29]	No	Age 10 and above	Alerts to phone and can send GPS location	Yes	$1412*
Embrace 2	Multi-modal - motion, electro-dermal, temperature	Wrist	Tonic clonic	International except certain areas†	Good performance – sensitivity 95% and FAR 0.2/day (phase 2) [34]	Yes – FDA and EPA	Age 3 and above	Alerts to phone and can send GPS location	Yes	$249 + recurring fees ranging from $9.90 - $44.90/ mo, MD prescription required
Seizure Link	Surface EMG	Biceps	Tonic clonic	US	Good performance – sensitivity 93.8% and FAR 0.67/day (phase 3) [35]	Yes – CE mark	Arm circum-ference >6 in.	Alerts to phone	Yes	$499 + replace-ment electrodes cost ~$40 - $45/ mo
SPEAC‡	Surface EMG	Biceps	Tonic Clonic	USA and Europe in VA and University Hospitals	Good performance – sensitivity 76% and FAR 2.52/day (in subgroup with proper placement sensitivity 100% and FAR 1.44/day) (phase 3) [36]	Yes - FDA	Age 18 and above	Alerts to text, email, or phone	Yes	$4500 per mo for 30–90 day duration, MD prescription required

Legend: FAR = false alarm rate. EMG = Electromyography, EEG = electroencephalogram. Note: all devices require a compatible smart phone.
* Conversion from original currency to dollars.
† North Korea, Mexico, China, Iran, Syrua, Sudan, and South Sudan.
‡ SPEAC is no longer commercially available.

control unit allowing the device to be portable, and some require an internet connection which allows remote alerting of caregivers. These devices would be able to detect seizures anytime of the day and at any location and would be ideal for people with epilepsy who are more independent and may at times be alone and wish to alert a designated person that they are having a seizure. Some devices can even send GPS locations through the smartphone application. They would also be able to track the number of seizures, which would be particularly useful for accurate seizure counts, which a clinician can then use to guide medical decisions or a research team can use to assess an outcome for a clinical trial. And similar to in-home detection devices, they would be able to alert a family member/caretaker during a nocturnal seizure to reduce the risk of SUDEP. Some devices take advantage of existing consumer electronics such as smart phones and smart watches with accelerometers or heart rate detectors, which a person with epilepsy may already own. Ambulatory detection devices are typically designed for adults and may

not be adaptable for younger children or infants. Ambulatory detection devices are also associated with higher false alarm rates related to daytime activities, though most ambulatory detection devices allow the wearer to cancel a false alert.

One of the main utilities of seizure detection devices is accurate seizure quantification for a clinician or a research team in a clinical trial. Two commercially available devices have been designed for this purpose, which include SPEAC, an ambulatory detection device using surface EMG, and Nelli, an in-home detection device using video motion. These devices are used for a limited duration (ranging from weeks to months) to provide an accurate quantification of seizure activity over the duration of use. Nelli is also able to record audio-video and could aid in determining if paroxysmal events are seizures or not. Of note, since the writing of this article, SPEAC is no longer commercially available.

Important preferences in choosing an optimal device include device cost, appearance, and comfort. Device cost range from a free application used with a smart phone or watch (seizure sync, seizario, epdetect) to high up-front costs over $1000 (*epi*-care free/mobile, epi-care 3000, nightwatch), or recurring fees (epi night nurse, smartwatch inspire, embrace 2, seizurelink). Device appearance and comfort depends on the detector location. For ambulatory detection devices, having a discreet, non-stigmatizing device is important for many people [27,28]. This has been a main barrier for the development of EEG or near-infrared spectroscopy based seizure detection devices which are typically worn on the head.

Another important factor to consider is seizure type. Almost all commercially available seizure detection devices have been designed to detect only tonic-clonic seizures. The only exception currently is Epihunter which is designed for absence seizures. One device, Nightwatch can detect tonic-clonic and major motor seizures. However only eight devices currently have peer-reviewed published data on performance [29–37] (Fig. 1), and only three of these devices have been evaluated prospectively in a natural environment. Performance data not evaluated in the natural environment should be interpreted cautiously. Taking this into account, wearable devices for detecting tonic clonic seizures are able to achieve a sensitivity of greater than 90% (Fig. 1a). For SPEAC, if the device is properly placed, it can achieve a sensitivity of 100%. The bed movement sensors (medpage and emfit) had a lower sensitivity (ranging from 11% to 63%). Emfit had better sensitivity in small prospective single center studies [37–39] but a recent large prospective natural environment study reported lower performance [32]. False alarm rate is more variable (Fig. 2b), but the majority of the devices had a rate of less than 1 per 24 h (with exception of Medpage and SPEAC). The false alarm rate is an important consideration and the tolerable threshold is variable between different people [40].

For the rest of the devices without peer reviewed published data on performance, it is unclear what their effectiveness is for detecting tonic-clonic seizures, and this is important to emphasize to patients. There may be indirect evidence supporting a specific detection mechanism, but the commercially available detector sensors and algorithms may be

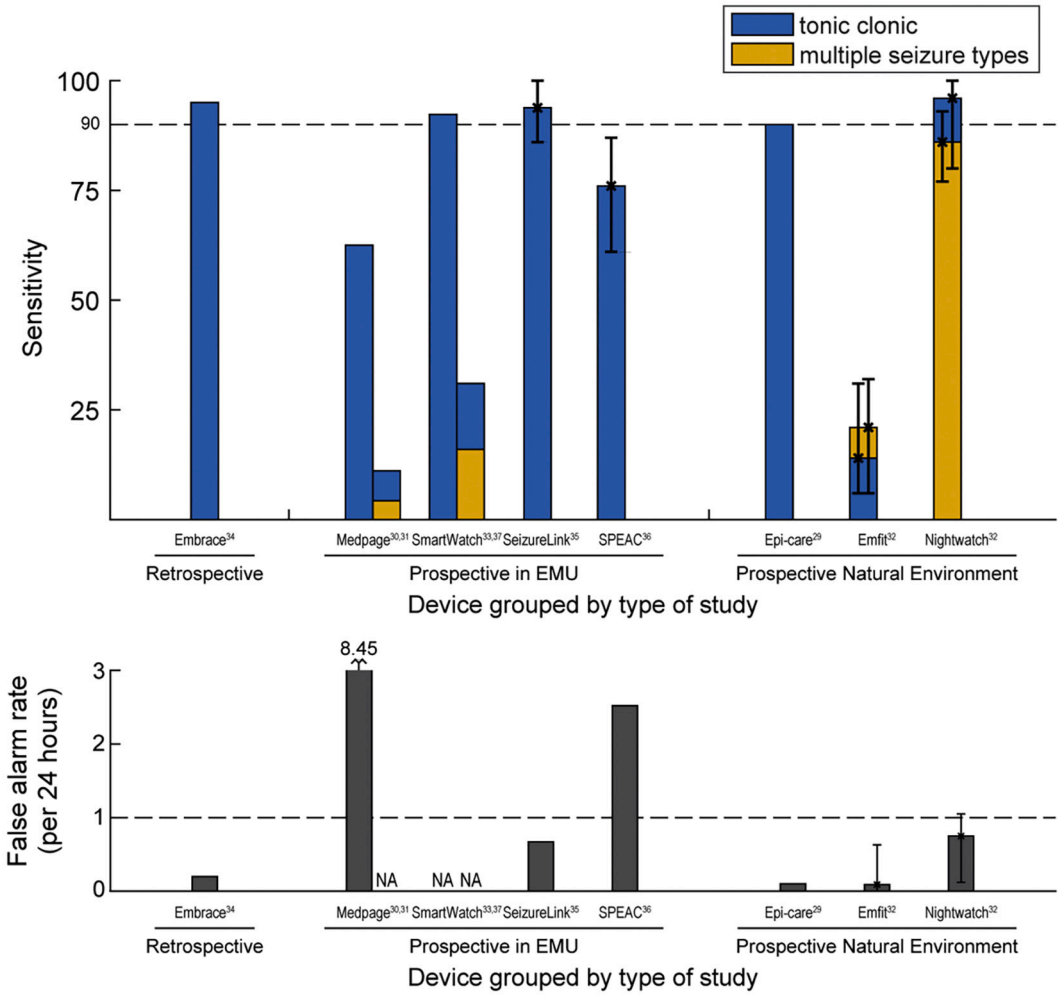

Fig. 2. Commercially available device performance, for devices with peer-reviewed published data [29,30,32–37,39]. Performance is given in terms of sensitivity (A) and false alarm rate (B) for each device, grouped by type of study (retrospective/offline analysis, prospective/real-time performance in an EMU, prospective/real-time performance in a natural environment. NA indicates that the false alarm rate was not available. Error bars represent 95% confidence intervals, if available.

different, and its effectiveness is unknown. Heart rate detector sensors rely on ictal tachycardia to detect seizures. Ictal tachycardia is common and can be seen in 82% of people with epilepsy [41]. Recent retrospective studies on ePatch [42,43], a heart rate detector under development, detected ictal tachycardia in convulsive seizures with greater than 90% sensitivity and a FAR of less than 1 alarm per 24 h. Video detectors with automated video analysis has also been shown in a retrospective study [44] to have 100% sensitivity and FAR of approximately 1.78 alarms per 24 h for convulsive seizures.

There are several devices that have been shown to detect other seizures types. Nightwatch, a multimodal device employing HR and 3-D accelerometry for in-home detection, was tested on tonic clonic seizures as well as other motor seizures such as tonic seizures, hypermotor seizures, and clustered myoclonic seizures in residental care facilities. It performed reliably in a prospective natural environment study, achieving an 86% sensitivity and FAR of 0.75 alarms per 24 h [32] (Fig. 1) compared to expert review of video. Other devices have not been able to show adequate performance for detecting motor seizures other than tonic clonic seizures [32,37,39]. No device has been shown to prospectively detect non-convulsive seizures. For non-convulsive seizures, there is only indirect evidence with variable performance. Autonomic changes do occur in some non-convulsive seizures, such as ictal tachycardia, as mentioned above, or other cardiovascular, respiratory, or electrodermal changes. These changes could be measured using EKG, oxygen saturation, or skin conductance. However, a recent review article found that unimodal autonomic algorithms could not reach acceptable performance due to high false alarm rates [45]. However, recent retrospective studies on ePatch [42,43], a heart rate detector under development, was able to achieve a sensitivity of 85–90% and FAR of less than 1 alarm per 24 h in a select group of responders who had prominent heart rate changes during their non-convulsive seizures. 45–58% of people with non-convulsive seizures were responders.

3.3. Novel technologies

There are many devices currently under development (Table 3) with a variety of detection mechanisms. Post-ictal apnea occurs with about 20% of all generalized convulsive seizures [46] and both central and obstructive apnea following convulsive seizures have been observed prior to death in several reports of SUDEP during video-EEG monitoring

Table 3
Selected devices under development.

Name	Company	Mechanism	Detector location	Website	Clinical Trials. Gov ID
Wearable Apnea Detection Device (WADD) [50]	Wearable Apnea Detection Device (WADD)	Apnea detector	Neck	https://sudep.org/wearable-apnoea-detection-device	
MJN-SERAS	MJN Neuroserveis	EEG	Ear	https://www.epilepsy.com/deviceapedia/mjn-seras	
SeizeIt2	EIT Health	EEG	Ear	https://eithealth.eu/project/seizeit2/	
EEGLE	CortexXus	EEG	Glasses	https://www.cortexxus.com	
Avertus	Avertus	EEG	Scalp	https://avertus.ca	
Epilog	Epitel	EEG	Scalp	https://www.epitel.com	NCT03745118
EPOC+, Insight, MN8	Emotiv	EEG	Scalp	https://www.emotiv.com	
MindWave Mobile Headset	NeuroSky	EEG	Scalp	https://store.neurosky.com/pages/mindwave	
Korwave	Korwave	EEG	Scalp	https://www.epilepsy.com/deviceapedia/korwave	
Epiminder	Epiminder	EEG	Sub-scalp	https://epiminder.com	
24/7 EEG SubQ	UNEEG medical	EEG	Sub-scalp	https://www.uneeg.com	
Neuronaute Smart Textile	Bioserenity	EEG and heart rate	Cap and shirt	https://www.bioserenity.com/en/neuro/	
Eysz	Eysz, Inc	Eye tracking	Eyes	https://eyszlab.com	
ePatch [42,43,62]	BioTelemetry	Heart rate	Chest	https://www.gobio.com/epatch/?gclid=Cj0KCQjwmIuDBhDXARIsAFITC_6XUGD1r4UlYGh83j4y7zbHAK2Gz1UFiCjA1dySoeQXx07P76vDzRAaAqp0EALw_wcB	
eSAP	RTI International	Heart rate, respiration, body orientation, temperature, electrodermal	Chest	https://www.rti.org/news/rti-international-continues-development-mobile-seizure-alert-system-epilepsy-patients	
GeneActiv	Activinsights	Motion	Wrist	https://www.activinsights.com/products/geneactiv/	NCT03745118
Actigraph	Actigraph	Motion	Wrist	https://www.actigraphcorp.com/actigraph-wgt3x-bt/	NCT01850498
Epilert [63]	Epilert	Motion	Wrist	https://epilert.io	
ProGuardian	LivaNova	Motion and heart rate	Chest	None	NCT01626599
Epiwatch	Apple/Johns Hopkins	Motion and heart rate	Wrist	https://www.hopkinsmedicine.org/epiwatch/epiwatch%20flyer.pdf	
Shimmer3	Shimmer Research	Motion and heart rate	Wrist	https://www.shimmersensing.com/assets/images/content/case-study-files/Research_Case_Study_-_Tele_Epilesy_and_Remote_Seizure_Monitoring.pdf	
Sensor Dots	Byteflies	Multi-modal - blood volume pulse, heart rate, motion, electrodermal, EMG, EEG	Multiple sites	https://www.byteflies.com	NCT03745118
Everion	Biovotion	Multi-modal - blood volume pulse, motion, electrodermal, temperature	Arm-band	https://www.biovotion.com/everion/	NCT03745118
Neuroon mask	Cymerteam Sp. Zo.o.	Multi-modal - EEG, eye tracking, pulse oxygenation, motion, temperature	Head over eyes	https://www.neuroon.com.br	
Bespoke sensor armband [64–66]	IMEC	Multi-modal – heart rate, motion, EMG, electrodermal	Arm-band and electrodes on chest	https://www.imec-int.com/en/articles/sensor-bracelet-detects-epileptic-seizures	

Legend: EMG = Electromyography, EEG = electroencephalogram.

[47–49]. An apnea detector would not detect seizures but could potentially alarm for impending SUDEP. Commercial devices are currently available to alarm for impending sudden infant death syndrome or sudden unexplained death in childhood (though no evidence exists that these devices can reduce risk or prevent death) and have been used by people with epilepsy with concerns of SUDEP. Examples include Neebo, which detects changes in heart rate, oxygenation, movement, and temperature, and Owlet which detects changes in heart rate and oxygenation, and Snuza which detects breathing movement, as well as many other devices. The Wearable Apnea Detection Device (WADD) [50] is reported under development for people with epilepsy.

EEG based detectors have the potential to detect multiple seizure types and development is underway for more discrete appearing devices [51–54], which range from ear pieces, to headbands, to small scalp adhesives. Multi-modal devices also have the capability to detect multiple seizure types with reduced false alarm rates. They utilize motion and autonomic change sensors with some combining EMG, EEG, eye tracking, or video [55,56]. Multi-modal smart textiles (e.g. t-shirt) are under development which can measure movement and autonomic changes and other parameters. Near infrared spectroscopy, which measures cerebral oxygen saturation, could be useful in detecting the hemodynamic changes that occur in the brain during seizures [57]. Audio based detectors could have the potential to pick up seizure related noises such as rhythmic sounds, disordered breathing, and ictal vocalizations [58]. Machine learning algorithms also have the potential to be personalized to an individual's seizure characteristics, improving accuracy and reducing false alarms [59–61].

3.4. Seizure forecasting and prediction

A major area of epilepsy research is aimed at seizure forecasting and prediction [67,68], as the unpredictability of seizures is one of the most disabling aspects of epilepsy. Seizure prediction focuses on whether a seizure will occur or not, while seizure forecasting focuses on identifying the time periods when there is a high probability of seizure. Long term ambulatory recordings from RNS devices and ambulatory intracranial EEG monitoring devices have provided evidence that seizures and interictal epileptiform activity have a clear circadian or multi-day patterns [69–71]. Studies using seizure diaries have also shown robust circadian and multi-day patterns [72,73]. There is even a subset of people with epilepsy who can predict their own seizures up to 6 h prior using a diary and premonitory features [74]. And a recent study using seizure diary data to forecast low and high seizure states found that the data was predictive in 50% of their cohort [73]. Thus personalized seizure forecasting utilizing data from seizure detection devices will likely be a future advantage of these devices. In regards to seizure prediction, a prospective study on NeuroVista, an implanted long term ambulatory intracranial recording device [75], has found that it is feasible. Pre-ictal heart rate increases have also been found in 36% of seizures, with a median onset 10.7 s prior to clinical or EEG signs [76]. Small case studies have also found pre-ictal hemodynamic changes using near-infrared spectroscopy [77–79]. Recent advances in biosensors and the ongoing development of multi-modal devices has now allowed for long-term ambulatory collection of EEG and other physiological data, which will advance the identification of the pre-ictal characteristics that can predict someone's next seizure.

4. Conclusions

Seizure detection devices could be an invaluable tool for certain people with epilepsy. There are numerous devices commercially available with varying detection mechanisms and characteristics. Clinicians should be familiar with the devices available to best counsel their patient's on whether a seizure detection device may be beneficial and what the optimal devices may be. Patient's should be informed if performance data on the device is available or unknown. There are ongoing advances in biosensor technologies and algorithms that will continue to improve the performance of these devices. In the future, seizure forecasting and prediction may be a possibility.

Funding

Author JS is funded by Finding a Cure for Epilepsy and Seizures (FACES) and the American Epilepsy Society (AES) for work unrelated to this study.

Declarations of interest

Author JS has no declarations of interest. Author DF receives salary support for consulting and clinical trial related activities performed on behalf of The Epilepsy Study Consortium, a non-profit organization. Dr. Friedman receives no personal income for these activities. NYU receives a fixed amount from the Epilepsy Study Consortium towards Dr. Friedman's salary. Within the past two years, The Epilepsy Study Consortium received payments for research services performed by Dr. Friedman from: Biogen, Cerevel, Cerebral, Crossject, Engage Pharmaceuticals, Eisai, Lundbeck, Pfizer, SK Life Science, and Xenon. He has also served as a paid consultant for Neurelis Pharmaceuticals and Receptor Life Sciences. He has received travel support from the Epilepsy Foundation. He has received research support from NINDS, Epilepsy Foundation, Empatica, Epitel, UCB, Inc. and Neuropace unrelated to this study. He serves on the scientific advisory board for Receptor Life Sciences. He holds equity interests in Neuroview Technology. He received royalty income from Oxford University Press.

Acknowledgements

None.

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