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At home EEG monitoring technologies for people with epilepsy and intellectual disabilities: A scoping review

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Declaration of Interests

The funder, UNEEG Medical UK Ltd, manufactures the 24/7 EEG™ SubQ device; a long-term subcutaneous implant for remote EEG monitoring of epilepsy. JDH and LB are employees of UNEEG.

ABSTRACT

Background: Conducting electroencephalography in people with intellectual disabilities (PwID) can be challenging, but the high proportion of PwID who experience seizures make it an essential part of their care. To reduce hospital-based monitoring, interventions are being developed to enable high-quality EEG data to be collected at home. This scoping review aims to summarise the current state of remote EEG monitoring research, potential benefits and limitations of the interventions, and inclusion of PwID in this research.

Methods: The review was structured using the PRISMA extension for Scoping Reviews and PICOS framework. Studies that evaluated a remote EEG monitoring intervention in adults with epilepsy were retrieved from the PubMed, MEDLINE, Embase, CINAHL, Web of Science, and ClinicalTrials.gov databases. A descriptive analysis provided an overview of the study and intervention characteristics, key results, strengths, and limitations.

Results: 34,127 studies were retrieved and 23 were included. Five types of remote EEG monitoring were identified. Common benefits included producing useful results of comparable quality to inpatient monitoring and patient experience. A common limitation was the challenge of capturing all seizures with a small number of localised electrodes. No randomised controlled trials were included, few studies reported sensitivity and specificity, and only three considered PwID.

Conclusions: Overall, the studies demonstrated the feasibility of remote EEG interventions for out-of-hospital monitoring and their potential to improve data collection and quality of care for patients. Further research is needed on the effectiveness, benefits, and limitations of remote EEG monitoring compared to in-patient monitoring, especially for PwID.

Keywords

Epilepsy; Remote Monitoring; Electroencephalography; EEG; Seizures, Home Care Services

INTRODUCTION

Background

Electroencephalography (EEG) is a key tool for monitoring epileptiform activity and seizures to diagnose and manage care for epilepsy [1]. Routine, out-patient EEG recordings are often not sufficient for patients who have a low frequency of clinically overt seizure activity [2], so accurate measurement often requires long-term monitoring in hospital. Video-EEG monitoring can provide valuable data to inform a patients' care, but requires long hospital stays - outside the patients' typical circumstances - and can cost thousands of US dollars equivalent to conduct [3–6]. Certain population groups - such as people with intellectual disabilities (PwID) - can experience particular difficulties with inpatient video-EEG monitoring.

There is a large population of PwID (approximately 1.5 million [7]) in the UK and there is significant comorbidity between epilepsy and ID. The prevalence of epilepsy in PwID or autism is 22.5%, compared to 0.6% in the general population, and 70% of PwID or autism have treatment resistant epilepsy, compared to 30% in the general population [8]. Despite this, the population of PwID and epilepsy remains underrepresented in research [9] and there is a lack of data on misdiagnosis relating to epilepsy in PwID [10]. PwID experience distinct barriers to seizure-related care, including communication and comprehension difficulties and discomfort or overstimulation in unfamiliar hospital environments [11,12], and are more likely to have brain abnormalities leading to non-seizure linked EEG disturbances and variations which can complicate diagnosis [13]. Remote EEG monitoring - the collection of EEG data over a period of time in an out-of-hospital setting - has the potential to improve the quality of care for PwID and the general population by minimising disruption to their daily lives, reducing the need for hospitalisation, and providing prolonged, high-quality, seizure-activity data.

Rationale

A preliminary review of the literature and previous reviews in this field is detailed in the review protocol [14]. In summary, while some reviews have examined at-home seizure detection [15–18] the authors did not identify any that included implantable devices. Other reviews examined specific scopes including wearable EEG electrodes [19], ultra long-term wearable or subcutaneous EEG [20], home video-EEG telemetry [21], and the quantification of mobility for remote EEG devices [22]. No reviews were identified - published or registered in the international database of prospectively registered systematic reviews (PROSPERO) - that provided an overview of remote EEG monitoring devices in general or for adult PwID and epilepsy in particular. This gap highlighted the need for an examination of the state of the field regarding remote EEG monitoring interventions and how they are being used to support PwID and epilepsy.

Aim and research questions

The aim of this scoping review was to identify and summarise the current state of research on remote EEG monitoring interventions in general, and for adult PwID and epilepsy in

particular, including the types of interventions, their benefits and limitations, and the strengths and weaknesses of the studies investigating them, to inform future directions for research and development. Specifically, the review focused on the research question: *What interventions are being evaluated and delivered to enable out-of-hospital EEG monitoring of epileptic seizures in adults, particularly those with intellectual or developmental disorders?*

METHODS

Scope

The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR; Supplemental Material 1) guidance [23]. The Population, Intervention, Comparator, Outcome, and Studies (PICOS) framework was used to develop the search strategy (see Table 1) and structure the review.

Table 1. PICOS framework

Population	The main population was adults (≥18 years old) with intellectual disabilities and epilepsy, but the inclusion criteria will include all adults with epilepsy to enable an overview of all potential remote EEG monitoring technologies that could be used in the PwID population
Intervention	Remote EEG monitoring interventions (including physical devices and software or algorithms used to analyse collected data)
Comparator	No comparator required
Outcome	The primary outcome was the evidence regarding seizure detection. As a variety of study types were expected, this outcome was defined broadly (e.g. including studies that evaluated the intervention's ability to detect seizures for the purposes of diagnosis or to accurately count seizures for the purposes of clinical management). Secondary outcomes included study characteristics, strengths, and weakness and intervention characteristics, benefits, and limitations.
Study types	All study types that evaluate a relevant intervention were eligible for inclusion. Protocols, reviews, meta-analyses, and conference or poster abstracts where no full text is available were excluded.

Search strategy

Six databases (PubMed, MEDLINE, Embase, CINAHL, Web of Science, and ClinicalTrials.gov) were searched by one author to identify relevant studies on 23 March 2022. To ensure that no relevant studies were missed or excluded in the first stage of screening, a hand search was conducted by an author with extensive experience in the field and awareness of the relevant literature and included in the full-text screen. Search terms were developed based on a preliminary review of the data and the search string was structured based on three main themes: population (MeSH OR Keywords) AND epilepsy

(MeSH OR Keywords) AND remote EEG monitoring (MeSH OR Keywords). An example of the search string (with the number of results returned) is provided in Supplemental Material B.

Eligibility criteria

The inclusion and exclusion criteria are detailed in Textbox 1. To provide a comprehensive summary of out-of-hospital EEG monitoring of epileptic seizures, we did not restrict the type of EEG monitoring to either implantable or not-implanted EEG electrodes. Despite differences in their use and monitoring time frames, both are used in out-of-hospital contexts to collect EEG data. Although the focus of the review was on PwID and epilepsy, the scope of the review was not limited to that population; to support future evidence generation on EEG monitoring for PwID, it was important to capture and summarise all technologies that are potential options for that population. To limit the scope of the review to current and upcoming remote monitoring technologies, only studies published in the past 10 years were eligible. This was a conservative estimate, as it enabled studies with data collected earlier to still be included, reducing the possibility of eliminating relevant interventions.

Textbox 1. Inclusion and exclusion criteria

Inclusion criteria

- Any adults (≥18 years old) with epilepsy (including but not limited to adult PwID and epilepsy)
- Interventions that provide at-home EEG monitoring of epileptiform activity or seizures; including wearable or implanted devices and studies
- Primary or secondary data analysis (e.g. use of previously collected datasets)

Exclusion criteria

- Studies focusing on paediatric populations
- Remote monitoring interventions for epilepsy that do not use EEG (e.g. electronic seizure diaries, motion sensors, video monitoring only)
- EEG interventions that are not aimed at providing home-based monitoring
- Studies that do not evaluate the intervention (e.g. protocols, reviews, abstracts without available full texts)
- Studies not published in English
- Studies published before 2011

Screening and article selection

References were exported to the citation management software EndNote X9, which was used to detect and remove duplicates. An initial keyword-based screening of references was conducted using the EndNote X9 search function. The remaining titles and abstracts were screened by four of the authors and a full-text review of the included studies was conducted by three of the authors, who discussed their decisions to determine final eligibility. Hand searches identified relevant papers that were not included in the full text review, so a second

screening of all the retrieved references was conducted using keywords from the search terms and eligible papers by one author.

Data extraction

Three reviewers extracted data from the included studies into a pre-developed form working as two independent entities (Table 2). In addition to characteristics about the study and the intervention, we extracted the main results reported by the included studies regarding seizure detection (eg, sensitivity, specificity, false-alarm rate, safety, percentage of seizures captured, success at answering clinical question), any data collected about acceptability or patient perceptions, and the benefits and limitations of the intervention.

Table 2. Data extraction

Article information	**Data to be extracted**
Study information	
	Year of publication
	Sample size (patients and seizures)
	Study type
	Target population (if specified)
	Study setting
Intervention	
	Type of intervention
	Description of intervention features / components
	Degree of mobility when using
	Duration of patient use
Evaluation	
	Main findings regarding seizure detection (eg. sensitivity, specificity, false-alarm rate, safety)
	Acceptability / patient perceptions
	Benefits of the remote EEG monitoring intervention
	Limitations of the remote EEG monitoring intervention
	Strengths and weaknesses of the study

Data analysis and synthesis

A descriptive analysis of the data extracted from the studies was conducted by three authors and summarised to provide a scoping overview of the state of the literature, the strengths and weaknesses, and implications for future research.

RESULTS

Study characteristics

The database and register search retrieved 34,127 references (see Supplemental Material 2). The EndNote X9 software was used to remove duplicates and conduct initial keyword screening (see Supplemental Material 3). The titles and abstracts of 301 studies were manually screened by one reviewer in Rayyan. Of these articles, 48 were selected for the full-text review and 11 were determined to be eligible for inclusion. Hand-searches by one author identified 8 more studies that were potentially eligible; after independent full-text review by two authors, 6 were eligible for inclusion. To refine the screening process and ensure these and other relevant papers were included, a second screening was conducted. In the second screening, 731 references were identified for title and abstract review after EndNote screening (see Supplemental Material 3). These references were manually screened using the Rayyan software by one reviewer; 177 duplicates were removed and 483 were excluded. The full texts of 58 papers that were not already included in the study were reviewed and 6 were included, for an overall total of 23 included studies. The reasons for exclusion in the full-text review stage are detailed in Figure 1.

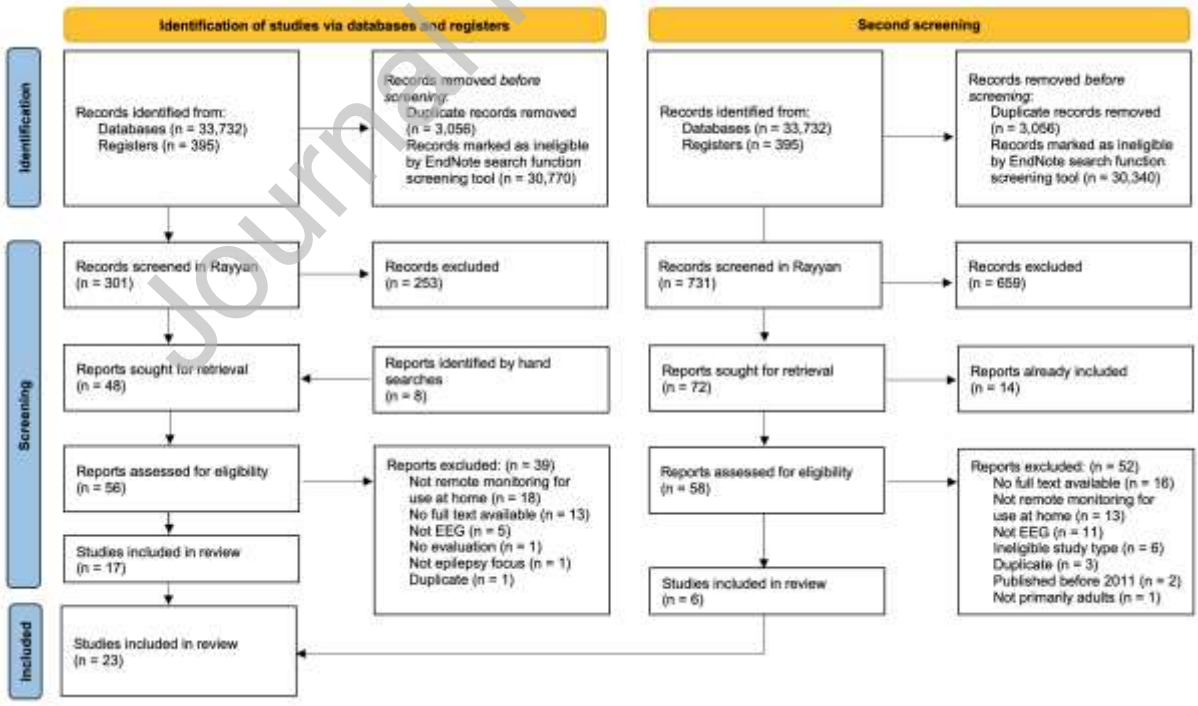

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram

A variety of study designs were used to evaluate the remote EEG monitoring interventions, but cohort designs were the most common (Table 3). Participant sample sizes ranged from 2 [24] to 324 [25] (excepting two studies that used large retrospective databases [6,26],with three quarters of the studies (17/23) having sample sizes smaller than 30. Most of the studies did not specify a target population beyond having epilepsy or needing prolonged EEG monitoring, but 4 studies specified drug-resistant (refractory) epilepsy [24,27–29], 2 specified focal epilepsy [30,31], and one mesial temporal lobe epilepsy [32]. Only 1 out of 17 studies specifically looked at a population with ID [33], but two other studies did include some patients with learning disabilities [34,35].

Table 3. Summary of study characteristics for included articles

Author, year	**Study type**	**Sample size (patients)**	**Sample size (seizures)**	**Target population**	**Study setting**
Arbasino et al. 2015 [30]	Observational study	90 *(30 per age group, 20-39, 40-59, 60+)*	N/A	Diagnosed with focal epilepsy	Home
Brunnhuber et al. 2014 [35]	Phase 1 = test-retest feasibility study Phase 2 = pre-implementation acceptability study	Phase 1 = 5 Phase 2 = 8	N/A	On video-EEG waiting list (excluding waiting for presurgical evaluation) Phase 2: *some had learning disabilities*	Home
Constantino et al. 2021 [31]	Validation study (training and testing ML algorithm)	22 *(12 evaluated)*	5226 *(excluded patients with fewer than 35 each)*	Diagnosed with focal epilepsy AND recommended for closed-loop neurostimulation therapy	Home
Cook et al. 2013 [28]	Multicentre clinical feasibility study	15	N/A	Lateralised epileptogenic zone, 2-12 partial onset seizures / month	Home
Cosgun and Celebi 2021 [36]	Validation study (training and testing classification model)	10 *(from EPILEPSIAE database)*	43 - training 26 - testing	Epilepsy, availability of long continuous recordings	Clinical
Dash et al. 2012 [5]	Prospective cohort study	101	Mean number of seizures (26 +/- 39 (range: 1-100)	Adults, who are eligible for inpatient video-EEG	Home
Elmali et al.	Prospective cohort	24	From 0 up	Adults with genetic	Home

2021 [37]	study		to >100 per patient	(idiopathic) generalized epilepsy (GGE/ IGE) and persisting typical absences (TA) or myoclonic seizures (MS)	
Faulkner et al. 2012 [25]	Retrospective cohort study	324	N/A	Patients who underwent outpatient aEEG	Home
Frankel et al. 2021 [38]	Cohort study	20 *(10 with seizures 10 without)*	24 in total (min: 1, mean: 2.4, median: 2, max: 6)	Adults who need long-term EEG evaluation	Home
Kandler et al. 2017 [34]	Non-randomised prospective cohort study	105 *(41 V-AEEG, 64 IPVT)*	N/A	Adults investigated to diagnose attacks or to obtain polysomno-graphy (PSG) prior to multiple sleep latency test (MSLT) *Some had learning disabilities*	Home
Lareau et al. 2011 [39]	Validation study	5	N/A	Healthy adults	Clinical
Nasseri et al. 2020 [40]	Cohort study	21	N/A	Diagnosed with epilepsy Healthy adults	Home OR clinical
Sawan et al. 2013 [24]	Validation study	2	N/A	Diagnosed with epilepsy	Not specified
Slater et al. 2019 [6]	Retrospective cohort study	13,958 (8,687 outpatient, 5,271 inpatient)	N/A	≥3 years old with at least 1 medical claim and a primary diagnosis of epilepsy or epilepsy-like conditions	Home and clinical
Stirling et al. 2021 [41]	Cohort study	5	0-27 seizures recorded per subject. Case study subject had 134 seizures over a 6-month period	Diagnosed with epilepsy	Home
Syed et al.	Retrospective	9221	N/A	Mostly adults, but also	Home

2019 [26]	cohort study			included children	
Titgemeyer et al. 2019 [42]	Exploratory pilot study	22	N/A	Adults undergoing noninvasive video EEG monitoring for clinical purposes	Clinical
Ung et al. 2017 [27]	Cohort study	15	N/A	Patients with drug-refractory epilepsy	Home
Viana et al. 2021a [43]	Cohort study	26	N/A	Adults with refractory epilepsy Healthy adults	Home
Viana et al. 2021b [29]	Case study	1	32	35 year old women with refractory epilepsy	Home
Wang et al. 2019 [33]	Non-randomized retrospective observational clinical trial	29	N/A	People with epilepsy AND an intellectual disability	Home
Weisdorf et al. 2018 [32]	Cohort study	4	86	Adults (18–90) with probable or definite mesial temporal lobe epilepsy and at least 1 seizure per week	Clinical
Weisdorf et al. 2019 [44]	Cohort study	9	N/A	Adults with temporal/frontotemporal seizure onset zone	Home

Intervention characteristics

There was a lot of diversity among the remote EEG monitoring interventions evaluated (see Table 4). A fifth of the interventions (5/24; as Sawan et al. [24] examined two different interventions) each were home video-EEG telemetry (HVET; scalp EEG electrode system accompanied by a home-based video recording device) [6,26,34,35,37] and subscalp EEG (EEG electrodes implanted below the scalp) [29,32,41,43,44], which were the most common. 4 studies each examined intracranial EEG interventions (electrodes placed on the surface of the brain) [24,27,28,31], wearable sensors (single electrodes attached to the scalp or wearable 'gaming-style' headsets) [36,38,40,42], and ambulatory EEG (standard EEG electrodes on a portable cap, without video recording) [5,25,30,33].Two studies used portable EEG-NIRS (near infrared spectroscopy) devices [24,39].

Most of the studies did not specify the degree of mobility associated with the type of remote EEG monitoring intervention they were evaluating. Several can be inferred to have unrestricted mobility - the sub-scalp EEG [29,32,41,43,44] and intracranial EEG [24,27,28,31] implants and the single-electrode wearables [36,38,40]. One of the ambulatory EEG studies claimed that patients could continue their normal daily activities [30], although the ambulatory EEGs and EEG-NIRS use a cap of EEG electrodes, often wired to a computer

or control module that, based on included photos, would appear to hamper mobility to at least some degree [24,39].

There was also a lot of variability in the duration of use, which ranged from 15 hours [5] to about 18 months [27]. More than half of the interventions (13/23) had durations less than 10 days [5,6,24–26,30,33–35,37,38,40,42], while a third (8/23) interventions supported monitoring over a couple months or more [27–29,31,32,41,43,44].

Table 4. Summary of intervention characteristics

Author, year	**Type of intervention**	**Device**	**Key features**	**Duration of use**
Arbasino et al. 2015 [30]	Ambulatory EEG	BS 2100, Micromed	● 16-channel ambulatory EEG recorder with 13 EEG electrodes	24 hours
Brunnhuber et al. 2014 [35]	Home video-EEG telemetry	Xltek Connex Laptop EEG system	● Not described in paper	M = 3 days
Constantino et al. 2021 [31]	Intracranial EEG	RNS NeuroPace	● 90 s recordings ● 4-channel ECoGs ● Online band-pass filtered at 4–125 Hz, sampled at 250 Hz and digitized by a 10-bit ADC	2.4-111.9 weeks (M=47.7)
Cook et al. 2013 [28]	Intracranial EEG	NeuroVista	● Electrodes: 2 silicon implantable lead assemblies with 8 platinum iridium contacts each ● Telemetry unit: titanium-encased, hermetically sealed unit implanted under the clavicle, implantable telemetry unit - sampled 16 channels acquired at 400 Hz ● Hand-held device: advisory system that wirelessly receives and analyses EEG data	4 months
Cosgun and Celebi 2021 [36]	Wearable sensor	*Data from EPILEPSIAE database*	● Proposed: machine learning algorithm and hardware architecture for seizure prediction using a single EEG electrode as unipolar ● RusBoosted Tree classifier	N/A
Dash et al. 2012 [5]	Ambulatory EEG	XLTEK Trex Ambulatory System	● 32 channels (24 AC, 4 differential, and 4 auxiliary DC) ● Sampling rate of 512 Hz ● Stores 96 hours of recordings	15-96 hours (M=32)
Elmali et al. 2021 [37]	Home video-EEG telemetry	XLTEK / Natus home video recording	● AMBU silver/silver chloride disposable electrodes attached using the 10-20 international system ● Double 5.5-size surgifix retaining	23-72 hours (M=47.5)

		equipment	bandage tied under the chin ● Event button for when patients feel a seizure starting	
Faulkner et al. 2012 [25]	Ambulatory EEG	Profusion ambulatory	● Digital 32-channel EEG system ● Standard 10-20 electrode placement	72-96 hours
Frankel et al. 2021 [38]	Wearable sensor	Epitel Epilog and Persyst	● Miniature, wireless, wearable electroencephalography (EEG) sensor (one-piece disposable, water-resistant "stickers") ● 4 sensors combined as part of Epitel's Remote EEG Monitoring platform (REMI) ● Data converted into a 10-channel REMI montage ● Persyst: clinical decision support software mobile interface for seizure detection	Up to 5 days (in study) Can be worn for up to 7 days continously
Kandler et al. 2017 [34]	Home video-EEG telemetry	XLTek / Natus	● Standard 10-20 EEG recordings ● Standard camera for in-patients ● High definition camera for home patients	48 hours
Lareau et al. 2011 [39]	Portable EEG-NIRS	*Developed prototype (8 channels)*	● Battery-powered, portable system with up to 32 EEG channels, 32 NIRS light sources, and 32 detectors ● Data from up to 128 optical input channels ● NIRS uses avalanche photodiodes (induce an internal gain when biased with a high voltage (>100 V) ● Data transmitted to a computer in real-time via a USB cable	Not specified
Nasseri et al. 2020 [40]	Wearable sensor	Epitel Epilog	● See 'Frankel et al. 2021' [38]	Up to 10 days
Sawan et al. 2013 [24]	Portable EEG-NIRS Intracerebral EEG	*Not specified*	● EEG-NIRS: 4 hr battery-powered ● 8-channel (8 electrodes) with 320 Hz sampling frequency ● 8 light-emitting diodes as light sources ● 8 avalanche photodiodes as light detectors for continuous-wave NIRS sensors recording at 20 Hz ● Implantable wireless icEEG: 32-channels with 24-bit resolution ● Radio frequency wireless link to the external equipments	EEG-NIRS: 24h Implant: ~3 weeks
Slater et al. 2019 [6]	Home video-EEG	*Not specified*	● Current Procedural Terminology code 95951 (monitoring for	M = 1.5 days

	telemetry		localization of cerebral seizure focus by cable or radio, 16 or more channel telemetry, combined EEG and video recording and interpretation, each 24h)	
Stirling et al. 2021 [41]	Sub-scalp EEG	Minder	• 2 implanted electrodes record differential EEG signals across two contacts at 250Hz • Telemetry unit: data and power transfer with external behind-the-ear process via radio frequency link • Mobile app / Cloud platform: captures audio and accelerometry data, stores and analyses data to enable seizure forecasting	At least 8 months (in study) Over 12 months in general
Syed et al. 2019 [26]	Home video-EEG telemetry	*Not specified*	• 25 electrodes (23 standard 10–20 EEG, two EKG) • A waist worn 200 samples/second EEG recording device with built-in patient-activated pushbutton event monitor • Two portable video-cameras that are synchronized with EEG recording, • Bluetooth radio hardware for remote real-time monitoring of video and EEG-tracings	M = 3 days
Titgemeyer et al. 2019 [42]	Wearable sensor (headset)	Emotiv EPOC	• Gaming EEG headset developed for advanced brain computer interface applications • Modified Combinatorial Nomenclature of the international 10–20 system with the following 16 channels: AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF42 and two references: P3 and P4	M = 30 minutes (pilot testing)
Ung et al. 2017 [27]	Intracranial EEG	NeuroVista	• 16 subdural electrodes: four strips of four medical grade platinum-iridium (90/10) contacts spaced either 10mm or 20mm apart • Telemetry unit: hermetically sealed subclavicular implant, samples channels at 400 Hz	M=18 months
Viana et al. 2021a [43]	Sub-scalp EEG	UNEEG SubQ	• Implant: three-contact lead wire (two-channel bipolar EEG) and a small ceramic housing • External recorder: data and power transfer via an inductive link • Two-channel EEG signal passes through a uniform amplifier • Sampling rate of 207 Hz	23-230 days (M=42)
Viana et al.	Sub-scalp	UNEEG	• See 'Viana et al. 2021a' [43]	230 days

2021b [29]	EEG	SubQ		(>7 months)
Wang et al. 2019 [33]	Ambulatory EEG	TMS (Twente Medical Systems)	• 24 electrodes of Ag/AgCL in 10–20 positions • Sampling rate of 100 Hz • Reported with BrainRT EEG acquisition system	24 hours
Weisdorf et al. 2018 [32]	Sub-scalp EEG	UNEEG SubQ	• See 'Viana et al. 2021a' [43]	3 months
Weisdorf et al. 2019 [44]	Sub-scalp EEG	UNEEG SubQ	• See 'Viana et al. 2021a' [43]	Up to 3 months (in study)

Seizure detection

The primary outcome of our review was the evidence reported by the studies about the remote EEG monitoring intervention's ability to detect seizures. This was operationalised differently among the studies; a wide range of outcome measures were used, including sensitivity, specificity, accuracy, false prediction rates, usefulness of the data for clinical management, and recording quality. Five of the studies did not evaluate seizure detection [6,24,27,37,39]; two were validation studies, one was examining signal variability post-implant, one was an economic analysis [6], and one used the remote EEG intervention as the gold standard to evaluate patients' self-assessment [37].

Typically, to evaluate the validity of a diagnostic measure, sensitivity and specificity are used to assess how well a tool can correctly identify positives and negatives. Sensitivity, specificity, and other associated measures were what we expected to find for outcomes evaluating the ability of a tool to accurately detect seizures. However, only four of the studies conducted comparisons of the performance of an intervention that enabled reporting of sensitivity, specificity, or false prediction rates - three studies of wearables, and one each of an intracranial EEG and an ambulatory EEG (Table 5) [28,33,36,38,42].

Table 5. Seizure prediction detection

	Sensitivity (%)	Specificity (%)	Prediction success (%)	False prediction rate (FP/hr)	High and low advisory (%)[a]
ML classifier for seizure prediction [36][b]	77.3	95.94	76.9 (20/26)	0.041	-
REMI automated seizure detection algorithm [38]	100	70	-	0.087[c]	-
Linear discriminant analysis (LDA) classifier of EEG signals in an ID population [33][d]	63.1-81.3	-	-	1.0[e]	-
Algorithm for advising	65-100[f]	-	-	-	H: 5-42

periods of high, moderate, and low seizure likelihood [28]	18-100[g]				L: 19-83 H: 3-41 L: 7-88
mEEG headset vs. video EEG	39 56	85 88			

[a]Rather than specificity, authors reported time spent in high and low advisories as a proportion of valid EEGs
[b]Sensitivity and specificity values are mean values
[c]For detecting individual focal onset seizures
[d]The LDA outperformed a comparator (SVM classifier) that is not reported here
[e]FPR reported is the median value
[f]Data collection phase (cross-validation estimate)
[g]Advisory phase (prospective performance at 4 months)

Two studies compared automated seizure detection to experts. One found that the algorithm performed with comparable accuracy to experts (0.84 and 0.80, respectively) [31] while in the other, the algorithm's mean sensitivity performed better than individual or consensus review, even when clinical decision support was provided [38]. However, it did have a higher false detection rate.

Two studies reported accuracy and area under the curve / area-under-precision-recall curve (AUC / AUPRC) scores, which reflect how well the model distinguishes between conditions. One seizure forecaster had high accuracy at distinguishing seizure from non-seizure hours (83%, AUC = 0.88), although it was only tested on 1 patient [41]. Another reported high model accuracy detecting ictal patterns in existing recordings (AUPRC = 0.84) and prospectively on new patients (AUPRC = 0.80) [31].

Six studies evaluated usefulness for clinical management; one study found that the clinical usefulness of seizure prediction using intracranial EEG was inconclusive [28] but the other 5 found positive impacts of the interventions. Two studies compared home and inpatient video-EEG and found that their clinical usefulness was comparable - in one study, both produced conclusive findings for 80% of patients (4/5 each) [35], in the other, both enabled accurate interpretation in over 90% of cases (97% or 40/41 for home patients and 91% or 58/64 for inpatients) [34]. The third and fourth studies found that A-EEG was useful for clinical management in 72% (73/101) [5], and 51% (112/219) [25] of cases, respectively. The fourth The remaining study qualitatively assessed seizure detection performance and observed that the seizure count collected provided information that would not have been captured from patient seizure diaries [44].

The two studies comparing home and inpatient video-EEG also assessed EEG recording quality and found no significant difference between them [34,35], with home video-EEG was as good, if not better, on all the measures except nighttime video quality in one study [34]. Two other studies also assessed EEG signal quality. A study of Epitel's Epilog wearable sensor classified EEG data by bandwidth (which indicates signal quality by estimating the highest frequency where noise and signal are significantly different) and found that 21.4% was good (>75 Hz) while 45.3% was 'marginal' (<35 Hz) [40] and two studies of UNEEG's

SubQ subcutaneous EEG found similar spectral characteristics to scalp EEG and stable signal quality over months [32,43].

One study examined the impact of age on the seizure detection ability of A-EEG and found an age difference in EEG detection of interictal epileptiform abnormalities when patients were awake, but not when they were asleep, with a lower sensitivity in older adults [30].

Acceptability

Nine of the 23 studies reported some type of patient experience or acceptability data. Only one study used a specific questionnaire (8-item Client Satisfaction Questionnaire), but this was for patients overall satisfaction with the comprehensive program, and was not specific to the A-EEG evaluated [5]. Three studies examined patients preferences and found that most, but not all, participants preferred home to inpatient video-EEG [34,35] and that wrist-worn devices (which did not measure EEG) were preferred to the single-electrode EEG wearable [40].

Other studies collected patient feedback anecdotally and found that, for the seizure advisory device, higher satisfaction was associated with lower proportions of time in the high likelihood advisory [28], that patients "wore [the EEG-NIRS] cap for several hours without annoyance" [24], and that sub-scalp EEG implants were generally well-tolerated and acceptable [41,44].

Three studies captured adverse events associated with implanted EEGs. One study of the SubQ sub-scalp EEG identified 13 adverse events, none of which were serious [44], and another (case study) reported that the device was well accepted "after a short adaptation period" with no serious adverse events [29]. One study of an intracranial EEG implant identified 11 adverse events in the first four months (2 of which were serious) and an additional 2 serious events within the first year [28].

Benefits and limitations of the interventions

Most of the studies detailed some of the potential benefits and limitations of the type of remote EEG monitoring intervention investigated. These have been compiled in Table 6, divided by the type of intervention.

Table 6. Benefits and limitations of remote EEG monitoring by intervention type

Type of intervention	Benefits	Limitations
Ambulatory EEG (including EEG-NIRS)	● Can produce good results in patients with a variety of indications [5] ● Can help diagnose epilepsy and inform care management changes [5,25] ● Enables monitoring during activity [24] ● Improved mobility and potential to undergo monitoring at home, compared to in-hospital monitoring [24]	● Scalp EEG not always effective at detecting certain seizure types [5] ● Lack of video recording, need to rely on patient/family history [5,25] ● No opportunity for trained clinician to observe ictal, pre-,

	• Outpatient A-EEG can be more cost-effective than inpatient A-EEG [25]	and post-ictal condition [5] • Artifact recognition is a potential issue [5,25] • System involves cap, wires, and control module - not ideal for normal activity [24]
Home video-EEG telemetry	• Recording conditions are close to real-life context [37] • Reduced travel time and associated costs or lost income [21,26] • Mitigates barriers if patient has caring responsibilities [21] • New patient groups, who could not have done inpatient video-EEG, can be identified and assessed [21,34] • Better suited for patients with special needs (home and usual carers better equipped to support patient) [21] • Opportunity to consult community professionals and provide multidisciplinary care (particularly in cases of people with learning disabilities) [21] • More cost effective than inpatient video-EEG (app. ⅔ the cost) [6,21,26,34] • Quieter and more familiar home environment beneficial for sleep monitoring [34] • Wait times and duration of monitoring can be shorter than for inpatient video EEG monitoring [6,26]	• Only a short 1-3 day "snapshot" view possible [37] • Home video quality slightly inferior than at hospital [21] • Can be more difficult for technicians to set up in patients' homes (no sedation if needed, must conduct risk assessment) [21] • Travel time (lost working time) for technician [21,34] • Patients can experience difficulties using video-EEG equipment [26,34] • Not suitable for patients who require sleep deprivation or anti-epileptic drug withdrawal pre-EEG for safety reasons [34]
Wearables	• Non-invasive remote monitoring option with low profile device [36] • More comfortable than multiple electrodes [36,38] • Potential for long-term monitoring, which could enable establishment of chronicity and seizure prediction (providing warning to patients with possible benefits for quality of life) [36,38] • Potential to be widely available [38] • Does not require much maintenance by patients or technicians (up to a week) [38] • Water resistant [38] • Potential to be used as a first step, to avoid unnecessary hospitalisation for monitoring [38,42] • Expected to be more cost-effective (but unproven) [38,42]	• The placement of the electrode that best predicts seizures varies between individuals [36] • Single (or few) electrode(s) means that data can be affected by artefacts or by a seizure originating in a different area [36,38,42] • Might not be suitable for seizure onset localisation [38] • Limited memory [36]
Sub-scalp EEG	• Minimally-invasive, with reduced implantation effect affecting early data [41] • Enables ultra long-term monitoring, which could benefit diagnosis and management and enable establishment of chronicity and seizure prediction [32,41,44] • Less noisy than scalp EEG [41]	• Susceptible to noise and artifacts from muscle activity [41] • Implantation not acceptable for all patients [41] • Data review requires time-intensive analysis a trained

	• High-quality signal comparable to scalp EEG [41] • Sensitive to small neurological events (e.g. sleep transients) [41,44] • No impact on mobility or need for long-term hospitalisation [41,43,44] • Does not require regular maintenance from technicians [43]	neurophysiologist to review, so extensive use will require effective seizure detection algorithms [29,41] • Only cover a small area of the cortical surface [32,44]
Intracranial EEG	• Can be used not just for monitoring but for seizure prediction, therapeutic electrical stimulation, responsive neurostimulation, and adaptive deep brain stimulation [27,31] • Allow for long-term monitoring [27,31] • No impact on mobility or need for long-term hospitalisation [27]	• Implantation effect (trauma, inflammation, or induced epileptiform activity or seizures) can affect early data recording [27] • Variability in signal properties [27] • Transmission quality from implant needs to be high [28]

Remote EEG monitoring in PwID

Although only three studies referred to PwID in their analyses [33–35] and only one was specifically focused on seizure detection in that population [33], they all reported positive perspectives on the use of remote EEG monitoring for PwID and epilepsy. Two of the studies highlighted potential benefits of the adoption of remote monitoring methods for PwID relating to the identification of new patient groups and provision of care to those who otherwise could not access it, patients' experience (less traumatic at home in familiar environment with normal care support than in hospital), and the opportunity for multidisciplinary consultations [34,35]. The third study used a retrospective dataset of scalp EEG recordings from PwID to develop an automated seizure detection algorithm. They found that although there were large differences in detection performance across patients, the seizure detector performed promisingly on a seizure pattern common in PwID (discharge with EMG activity) and had good sensitivity for seizures lasting over a minute [33].

DISCUSSION

Summary of findings

The review identified 23 studies that evaluated remote EEG monitoring interventions for adults with epilepsy, although only 3 studies considered the impact of remote EEG monitoring on PwID and epilepsy. There were multiple types of remote EEG monitoring technologies identified, including ambulatory EEG, home video-EEG, wearable electrodes, sub-scalp EEG, and intracranial EEG. At-home wearable EEG monitoring can be as bulky as standard outpatient EEG caps and wires, but with attached control modules that make it possible to remain at home, to single electrode patches that can be placed discreetly on the scalp. Implants range from a minimally invasive subscalp electrode to full intracranial electrode arrays. This highlights the range of remote EEG monitoring options available, varying in invasiveness, signal quality, and enabled mobility. The studies examined a variety of different outcome measures, with only four examined the interventions' sensitivity at

detecting seizures. About half of the studies reported something about patient acceptability, but none measured it robustly. There were a variety of benefits and limitations for each of the intervention types; in general, remote EEG monitoring produced useful results, often largely comparable to inpatient recordings, and patient mobility and experience were frequently mentioned as benefits. Two studies highlight potential cost benefits of home, compared to inpatient, video- EEG monitoring. A common limitation was that a small number of localised electrodes might not be able to capture all seizures, depending where they originate.

Strengths and weaknesses of the studies

Few of the studies reported their strengths, which is a limitation, as it impedes interpretation of study quality by readers. Certain study design strengths were identified and extracted by reviewers, including the use of a comparison - whether between patients and healthy controls [40], home or clinically-based EEG monitoring [21], or epileptologist or algorithmic review [38], relatively large sample sizes or datasets [5,31,34], and the inclusion of a variety of epilepsy types to improve generalisability [41].

The most prevalent methodological weakness identified was a small sample size. Only two studies had sample sizes greater than 100 participants [5,34] and most had fewer than 30 participants. Even among the studies with larger sample sizes, subgroup analyses had fewer participants, limiting the validity of results. This is a significant problem because it affects how well we can interpret the results. Other limitations included a lack of clarity in reporting - for example, the order of intervention types, whether drug changes during the study were tracked, and whether inpatient or remote EEG monitoring data was used in the analysis. Other limitations were particular to the study design; as there were a variety of study types included in the review, there were a variety of limitations reported by the individual studies. Examples of reported limitations included: early conclusion of the study [28], a limited number of channels which limits interpretation of the data [5], a lack of statistical analysis and generalisability due to sample size, population, or epilepsy type included [6,29,32,34,38,42,44], a lack of reviewer experience using and interpreting data from the monitoring system [38,39], limited validation or analysis due to a lack of time, reviewers, or resources [38,41,44], a lack of randomisation (resulting in potential sampling bias) [33,34], data about the remote monitoring system collected in a clinical setting rather than at home [24,38,39], and different implant locations between healthy subjects and controls [43].

Another potential limitation is that many of the studies only evaluated the remote EEG monitoring intervention over a limited period of time (the duration of use for half of the interventions was less than 10 days). While this duration was often limited by logistical factors (such as battery life), these interventions provide a more limited snapshot of epileptic brain activity than longer-term monitoring interventions. However, long-term monitoring may not be necessary for all patients, so certain remote monitoring types may be more or less appropriate depending on the particular clinical case.

Strengths and limitations of the review

This review is the first to provide a comprehensive overview of remote EEG monitoring interventions designed for use in non-clinical settings. A strength is that the review was conducted by multiple authors working independently and the collaboration between researchers with expertise in digital health, epilepsy, and PwID, to ensure that the technical aspects of the studies were interpreted correctly. However, the limited number of included studies considering PwID, and the heterogeneity of study designs and remote EEG monitoring intervention types made it difficult to conduct a rigorous comparison of the effectiveness, benefits, and limitations of certain types of intervention compared to others. As a review of published literature, it also may have excluded newly-developed commercial systems that may not have been clinically investigated yet.

The search was designed to focus on out-of-hospital EEG monitoring; however, a few of the studies reviewed at the full-text screening stage were examining interventions intended for home use in clinical settings. After discussion, the authors came to a consensus to retain these studies because we decided that, at this stage, this information was relevant and useful to include to demonstrate the state of the field. As the main focus of the search and screening was to identify evaluations of out-of-hospital EEG monitoring interventions, this review does not claim to have captured all studies that examined EEG monitoring devices (which could potentially be used out-of-hospital) in clinical settings.

Conclusion and future research

There is a growing number of studies examining remote EEG monitoring tools, particularly in recent years. This review demonstrates the variety of different types of remote EEG monitoring tools available, which fall into two main categories - wearable or implantable. Several studies examined the potential use of this remote monitoring opportunity to provide seizure prediction that would not be possible with only short-term, episodic EEG monitoring. This is likely to become an even bigger element of the research, as the emphasis on personalised and preventive medicine grows.

Likewise, some studies were beginning to examine the potential of remote EEG monitoring to support underserved population groups, such as PwID and epilepsy. This is a particularly important area of investigation, as a large portion of PwID also have epilepsy; PwID also have a higher risk of Sudden Unexpected Death in Epilepsy (SUDEP) than the general population [45–47]. PwID have a high prevalence of key risk factors, such as nocturnal seizures and a lack of nighttime surveillance [46]. The use of home-based remote monitoring systems could potentially be used to support PwID in the long-term and improve our understanding of SUDEP, risk factors in the PwID population, and how they could potentially be mitigated. It will be important to investigate which remote EEG monitoring interventions are best suited for PwID, both in terms of accurately detecting epileptic activity and seizures, which can be more complex in PwID, and in terms of acceptability. Acceptability will be a key area for future research of the use of such remote monitoring interventions, especially for PwID, and research is needed to address the particular challenges of implementing such interventions in that population (for example, how the intervention can

be explained most clearly to get their consent or assent, and how the intervention can be implemented so that it causes minimal interference to their lives). Future research should also continue to explore the benefits and challenges of such remote EEG interventions for different types of people, so that inpatient resources can be prioritised to those who will most benefit from them and people who experience difficulties and disruption due to inpatient stays can receive high-quality care in a more familiar setting.

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SUPPLEMENTAL MATERIAL

Supplemental Material 1. PRISMA-ScR Checklist

Supplemental Material 2. Search record

Database	Search string	Results
PubMed	((Adult[MeSH Terms] OR Persons with Mental Disabilities[MeSH Terms] OR Intellectual Disability[MeSH Terms]) OR (Adult[Title/Abstract] OR adults[Title/Abstract] OR "developmental disabilit*"[Title/Abstract] OR "learning disabilit*"[Title/Abstract] OR "intellectual disabilit*"[Title/Abstract] OR "learning disorder*"[Title/Abstract] OR "developmental disorder*"[Title/Abstract] OR "special need*"[Title/Abstract] OR "mental retardation"[Title/Abstract] OR autis*[Title/Abstract] OR "Down syndrome"[Title/Abstract] OR "fetal alcohol"[Title/Abstract]) NOT (child*[Title/Abstract] OR pediatric[Title/Abstract] OR paediatric[Title/Abstract] OR adolescen*[Title/Abstract] OR teen*[Title/Abstract])) AND ((Epilepsy[MeSH Terms] OR Seizures[MeSH Terms]) OR (Epilepsy[Title/Abstract] OR seizure[Title/Abstract] OR epileptic[Title/Abstract] OR convulsion[Title/Abstract] OR ictal[Title/Abstract] OR preictal[Title/Abstract] OR postictal[Title/Abstract] OR interictal[Title/Abstract] OR epileptiform[Title/Abstract])) AND ((Monitoring, Ambulatory[MeSH Terms] OR Electrodes, Implanted[MeSH Terms] OR Electroencephalography[MeSH Terms]) OR ((("Remote monitor*"[Title/Abstract] OR implant*[Title/Abstract] OR sensor*[Title/Abstract] OR wearable*[Title/Abstract] OR device*[Title/Abstract] OR detection*[Title/Abstract] OR alert*[Title/Abstract] OR home[Title/Abstract] OR mobile[Title/Abstract]) AND (EEG[Title/Abstract] OR electroencephalograph*[Title/Abstract] OR seizure*[Title/Abstract])) OR "Long-term electroencephalographic monitoring"[Title/Abstract] OR LTM[Title/Abstract] OR "continuous electroencephalographic monitoring"[Title/Abstract] OR "continuous EEG"[Title/Abstract] OR "intracranial EEG"[Title/Abstract] OR "intracranial electroencephalography"[Title/Abstract] OR iEEG[Title/Abstract] OR "ambulatory EEG"[Title/Abstract] OR "ambulatory electroencephalography"[Title/Abstract] OR "subcutaneous EEG"[Title/Abstract] OR "subcutaneous electroencephalography"[Title/Abstract] OR "subscalp EEG"[Title/Abstract] OR "subscalp electroencephalography"[Title/Abstract] OR "subgaleal EEG"[Title/Abstract] OR "subgaleal electroencephalography"[Title/Abstract] OR "subdermal electroencephalography"[Title/Abstract] OR "subdermal EEG"[Title/Abstract] OR "epicranial EEG"[Title/Abstract] OR "epicranial electroencephalography"[Title/Abstract] OR "epiosteal EEG"[Title/Abstract] OR "epiosteal electroencephalography"[Title/Abstract] OR "scalp-based EEG"[Title/Abstract] OR "scalp-based electroencephalography"[Title/Abstract] OR "behind the ear EEG"[Title/Abstract] OR "behind the ear electroencephalography"[Title/Abstract]))	20,497* First 10,000 (sorted by 'Best Match') downloaded to EndNote

Web of Science Core Collection [a,b]	((Adult OR "Persons with Mental Disabilities" OR adults OR "developmental disabilit*" OR "learning disabilit*" OR "intellectual disabilit*" OR "learning disorder*" OR "developmental disorder*" OR "special need*" OR "mental retardation" OR autis* OR "Down syndrome" OR "fetal alcohol") NOT (child* OR pediatric OR paediatric OR adolescen* OR teen*)) AND (Epilepsy OR seizure OR epileptic OR convulsion OR ictal OR preictal OR postictal OR interictal OR epileptiform) AND ((monitoring NEAR/2 ambulatory) OR (electrode NEAR/2 implant*) OR (("Remote monitor*" OR implant* OR sensor* OR wearable* OR device OR detection OR alert) AND (EEG OR electroencephalograph* OR seizure)) OR "Long-term electroencephalographic monitoring" OR LTM OR "continuous electroencephalographic monitoring" OR "continuous EEG"OR "intracranial EEG"OR "intracranial electroencephalography" OR iEEG OR "ambulatory EEG" OR "ambulatory electroencephalography" OR "subcutaneous EEG" OR "subcutaneous electroencephalography" OR "subscalp EEG" OR "subscalp electroencephalography" OR "subgaleal EEG" OR "subgaleal electroencephalography" OR "subdermal electroencephalography" OR "subdermal EEG" OR "epicranial EEG" OR "epicranial electroencephalography" OR "epiosteal EEG" OR "epiosteal electroencephalography" OR "scalp-based EEG" OR "scalp-based electroencephalography" OR "behind the ear EEG" OR "behind the ear electroencephalography")	1,377
Medline (Ovid)	((Adult/ or Persons with Mental Disabilities/ or Intellectual Disability/) or ((Adult or adults or "developmental disabilit*" or "learning disabilit*" or "intellectual disabilit*" or "learning disorder*" or "developmental disorder*" or "special need*" or "mental retardation" or autis* or "down syndrome" or "fetal alcohol") not (child* or pediatric or paediatric or adolescen* or teen*)).ti,ab.) AND ((Epilepsy/ or Seizures/) or (Epilepsy or seizure or epileptic or convulsion or ictal or preictal or postictal or interictal or epileptiform).ti,ab.) AND ((Monitoring, Ambulatory/ or Electrodes, Implanted/ or Electroencephalography/) or ((("Remote monitor*" or implant* or sensor* or wearable* or device* or detection* or alert* or home or mobile) and (EEG or electroencephalograph* or seizure*)) or "Long-term electroencephalographic monitoring" or "continuous electroencephalographic monitoring" or "continuous EEG" or LTM or "intracranial EEG" or "intracranial electroencephalography" or iEEG or ((ambulatory or subcutaneous or subscalp or subgaleal or subdermal or epicranial or epiosteal or "scalp-based" or "behind the ear" or "behind-the-ear") and (EEG or electroencephalography))).ti,ab.)	17,828* First 10,000 downloaded to EndNote

Embase (Ovid)	((Adult/ or Persons with Mental Disabilities/ or Intellectual Disability/) or ((Adult or adults or "developmental disabilit*" or "learning disabilit*" or "intellectual disabilit*" or "learning disorder*" or "developmental disorder*" or "special need*" or "mental retardation" or autis* or "down syndrome" or "fetal alcohol") not (child* or pediatric or paediatric or adolescen* or teen*)).ti,ab.) AND ((Epilepsy/ or Seizures/) or (Epilepsy or seizure or epileptic or convulsion or ictal or preictal or postictal or interictal or epileptiform).ti,ab.) AND ((Monitoring, Ambulatory/ or Electrodes, Implanted/ or Electroencephalography/) or ((("Remote monitor*" or implant* or sensor* or wearable* or device* or detection* or alert* or home or mobile) and (EEG or electroencephalograph* or seizure*)) or "Long-term electroencephalographic monitoring" or "continuous electroencephalographic monitoring" or "continuous EEG" or LTM or "intracranial EEG" or "intracranial electroencephalography" or iEEG or ((ambulatory or subcutaneous or subscalp or subgaleal or subdermal or epicranial or epiosteal or "scalp-based" or "behind the ear" or "behind-the-ear") and (EEG or electroencephalography))).ti,ab.)	18,167* First 10,000 downloaded to EndNote
CINAHL	(MH (Adult OR Persons with Mental Disabilities OR Intellectual Disability) OR AB (Adult OR adults OR “developmental disabilit*” OR “learning disabilit*” OR “intellectual disabilit*” OR “learning disorder*” OR “developmental disorder*” OR “special need*” OR “mental retardation” OR autis* OR “Down syndrome” OR “fetal alcohol”) NOT (child* OR pediatric OR paediatric OR adolescen* OR teen*))) AND (MH (Epilepsy OR Seizures) OR AB (Epilepsy OR seizure OR epileptic OR convulsion OR ictal OR preictal OR postictal OR interictal OR epileptiform)) AND (MH (Monitoring, Ambulatory OR Electrodes, Implanted OR Electroencephalography) OR AB (((“Remote monitor*” OR implant* OR sensor* OR wearable* OR device* OR detection* OR alert* OR home OR mobile) AND (EEG OR electroencephalograph* OR seizure*)) OR “Long-term electroencephalographic monitoring” OR “continuous electroencephalographic monitoring” OR “continuous EEG” OR LTM OR “intracranial EEG” OR “intracranial electroencephalography” OR iEEG OR ((ambulatory OR subcutaneous OR subscalp OR subgaleal OR subdermal OR epicranial OR epiosteal OR “scalp-based” OR “behind the ear” OR “behind-the-ear”) AND (EEG OR electroencephalography))))	2,355
ClinicalTrials.gov	(EEG OR electroencephalography) | Epilepsy	395

Supplemental Material 3. Endnote search criteria

First screening

Pass[a]	Search string	# of references remaining
1	Any Field = NOT (child OR children OR pediatric OR paediatric OR adolescent OR adolescents OR teen OR teenager OR teenagers))	21,994
2	Title OR Abstract = (epilepsy OR seizure OR epileptic OR convulsion OR ictal OR preictal OR postictal OR interictal OR epileptiform)	17,287
3	Title OR Abstract= (electroencephalography OR EEG)	6,300
4[b]	Any Field = (home OR remote monitor OR ambulatory OR implant OR wearable OR mobile)	1,684
5[b]	Any Field = (continuous OR intracranial OR subscalp OR subcutaneous OR subgaleal OR subdermal OR epicranial OR scalp-based OR behind the ear)	(Pass 4 found 1,037; pass 5 found 924)
6	Any Field = NOT (animal OR mice OR mouse)	1,476
7	Year = Is greater than or equal to (2011)	955
8	Title = NOT (protocol OR review OR meta-analys*)	938
9	Any Field = NOT (rodent OR rat OR rats OR equine OR horse OR canine OR dog OR pet)	908
10	Any Field = NOT (child OR paediatric OR pediatric OR natal OR neonatal OR infant OR baby OR teen OR adolescent)	901
11	Any Field = NOT (case report) OR Title = NOT (conference OR congress)	679
12	Abstract = NOT (inpatient OR in clinic OR in hospital OR admitted OR hospital monitor)	620
13	Any Field = (home OR outpatient OR wearable OR remote monitor OR implant OR out of hospital)	301

[a]Each pass was conducted on the subset of studies retrieved in the previous pass
[b]EndNote limits searches to 10 terms, so passes 4 and 5 were conducted separately and then combined, with duplicates removed

Second screening

Pass[a]	Search string	# of references remaining
1	Any Field = NOT (child OR children OR pediatric OR paediatric OR adolescent OR adolescents OR teen OR teenager OR teenagers))	21,994
2	Title = EEG OR seizure OR epilepsy OR electroencephalogra	13,854

3	Any Field = home OR remote OR intracranial OR long-term OR sub-scalp OR ambulatory OR wearable OR intellectual disab	2,226
4	Title = NOT (child OR paedia OR pedia OR juvenile OR animal OR infant OR *tomy OR surg*)	1,968
5	Title = home OR remote OR long-term EEG OR prediction OR ambulatory OR wearable OR intracranial OR wireless OR detection OR subcutaneous	731
Manual screening in Rayyan		
6	Duplicates removed in Rayyan (n = 177)	555
7	Published within the last 10 years (2011-Feb 2023)	489
8	Title and abstract screening in Rayyan	72
9	Articles not already included	58

Declaration of Interests

The funder, UNEEG Medical UK Ltd, manufactures the 24/7 EEG™ SubQ device; a long-term subcutaneous implant for remote EEG monitoring of epilepsy. JDH and LB are employees of UNEEG.