Research article

Home-video EEG monitoring in a pediatric setting

Yael Michaeli [a,*], Lubov Blumkin [a,b], Mordekhay Medvedovsky [c,d], Ilan Dalal [b,e], Andreea Nissenkorn [a,b]

[a] Pediatric Neurology Unit, Edith Wolfson Medical Center, Holon, Israel
[b] Pediatric Department, Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel
[c] Department of Neurology and Agnes Ginges Center for Human Neurogenetics, Hadassah Medical Organization, Jerusalem, Israel
[d] The Faculty of Medicine, Hebrew University of Jerusalem, Jerusalem, Israel
[e] Pediatric Department, Edith Wolfson Medical Center, Holon, Israel

A R T I C L E   I N F O

A B S T R A C T

Introduction: Pediatric video-EEG monitoring is a standard procedure in epilepsy clinics, typically conducted in in-hospital settings.However, hospitalizationis sometimesunnecessary and imposes a burden on children and their families. In response to the rise of telehealth, home video-EEG monitoring has emerged, utilizing portable EEG equipment and video-cameras.
Objective: The aim of this study was to assess the feasibility of home video-EEGin a pediatric population.
Methods: We conducteda prospective pilot study of twentyhome video-EEG tests in children. We evaluated the quality of EEG and video recordings using a 5-point scale.Demographic, clinical and quality data were comparedto a similar group undergoing in-hospital video-EEG monitoring.
Results: Twenty children aged 2.1–17.2 years (mean 9.57 ± 1.01), 12 females (60 %), underwent home video-EEG. A higher proportion of children with intellectual disability/autism were observed in the home-EEG group compared to the in-hospital group: 12 patients (60 %) vs. 5 (25 %) ($p < 0.05*$, Fisher exact test). In the ambulatory group patients with developmental and epileptic encephalopathy were overrepresented (7 i.e., 35 % vs. 0), while those withself-limited childhood epilepsy were more prevalent in the in-hospital group (5 i.e., 25 % vs 0) ($p < 0.05*$, Chi square). In the ambulatory group the reasons for referral were seizure localization/classification in 11 patients (55 %), paroxysmal event classification in 5 (25 %) and quantification of sleep epileptic activity in 4(20 %),similar to the in-hospital group (40 %, 40 % and 20 % respectively, $p > 0.05$, Chi square). The quality of the EEG recording was higher compared to in-hospital tests: median 5 [IQR 3.25–5] vs 4[IQR 3–4] ($p < 0.05*$, Mann-Whitney *U* test), while the quality of video recording was lower compared to in-hospital recordings: median 3[IQR 2.25–4] vs 5[IQR4-5] ($p < 0.01**$, Mann-Whitney *U* test).
Conclusions: Home video-EEG monitoring is apromising option forlong-termpediatric EEG monitoring, particularlyfor children with special needs.

1. Introduction

Video-EEG telemetry is a standard procedure in epilepsy clinics, typically performed as an inpatient procedure within the epilepsy monitoring units. While adult patients often undergo monitoring to classify and localize seizures, children are frequently referred to classify paroxysmal events (epileptic vs. non-epileptic) and quantify nocturnal epileptic activity, particularly to rule out electrical status epilepticus during slow-wave sleep (ESES). Children's monitoring periods are shorter, typically 24 h, and are often conducted in regular pediatric wards. Hospitalization for pediatric video-EEG monitoring is occasionally unnecessary and can be burdensome, especially for children with special needs.

Over the past decade, two methods of home video-EEG telemetry have evolved for both adults and children [1–5]. The first method includes supervised setups in patients' natural environments, with daily medical team visits. The second method is an ambulatory or mobile video-EEG, where electrodes are applied in a healthcare facility, and patients take home portable EEG recorders and video-cameras [3–6]. Both methods can be web-integrated (cloud-based home video-EEG monitoring), allowing online access of caregivers to the recording and connection with the patient [4].

The objective of this study was to assess the feasibility of ambulatory video-EEG telemetry in our Pediatric Epilepsy Clinic population.

2. Materials and methods

Amid the COVID-19 pandemic, which prompted the increased use of telemedicine, we examined the feasibility of ambulatory video-EEG telemetry in our Pediatric Neurology Unit at the Edith Wolfson Medical Center in Israel. Between June–December 2021, we conducted a pilot study comprising 20 ambulatory recordings, facilitated by a grant from the Ministry of Health's digitalization fund. We employed the Morpheus Home LTM kit, which includes a cordless 34-channel EEG recording system and a portable full HD video-camera purchased for this purpose.

2.1. Inclusion criteria

Patients enrolled for home video-EEG telemetry were selected from those referred to our in-hospital video-EEG service based on the following criteria.

1. No need for reducing antiseizure medication, cardiorespiratory monitoring, or an open intravenous line.
2. Absence of anticipated need for rescue medication.
3. Explicit preference from patients or their families for home monitoring.
4. Medical team assessment indicating the family's ability to manage the technology.

2.2. Procedure

Patients visited the Pediatric Neurology Unit for electrode placement and received training on the test, including instructions on operating the portable camera at home. The electrodes were attached with Tensive® conductive adhesive gel and secured with bandage and a mesh, in a similar mode as the in-house video EEG. Families were provided with a written flowchart with detailed instructions and images of the camera setup. This process took one to 2 h and was conducted by two technicians. Children were sent home with attached electrodes and a closed camera, kept in a carry-on bag. Families were responsible for opening the camera at home and placing it in the room where the child usually engaged in daily activities (e.g., living room, bedroom, kitchen). The caregivers received standard seizure diaries for event annotation, similar to those used in –hospital, but there was no event button to be pressed in the home setting. After 24 h, the child returned to the Pediatric Neurology Clinic to return the recording system and remove the electrodes. The test was downloaded and integrated into the regular EEG hospital dataset. EEG recordings encompassed the entire duration during which the child had electrodes attached, from the start of the test in the hospital until its return the following day.

Table 1
Quality ranking score of EEG and video recording.

Score	EEG recording quality	Video recording quality
0	No recording	No recording
1	Not informative, 3 or more electrode detachment	Not informative, clinical events not detected on movie or camera not recording for significant period
2	Partially informative, 2 electrode detachment	Partially informative, clinical events detected on camera, but relevant body parts do not appear
3	Fully informative, significant artefacts part of the time or 1 electrode detachment	Fully informative, clinical events detected with all relevant body parts, camera not recording for short period
4	Good quality and informative, minor artefacts	Good quality of picture and luminosity, highly informative, relevant body parts appear in movie
5	Excellent quality and highly informative	Excellent quality of picture and luminosity, highly informative, all relevant body parts appear in movie

Video and audio recordings included only periods when the camera was actively operated by the family.

2.3. Outcome measures

The quality of the EEG and video recordings wasreviewed by a single rater, AN -a Pediatric Neurologist with special interest in epilepsy.The recordings were scoredon a 5-point scale each(Table 1).EEG and video scores, along with demographic and clinical datawere compared to a similar group of 20 patients undergoing in-hospital video-EEG telemetry during the same period.There was no randomization between the two groups. It was not possible to blind the scoring because the video setting (home or hospital) was obvious to the observer.

2.4. Statistical analysis

Descriptive statistics wereused to tabulate the parameters. Numerical parameters were compared using the unpaired *t*-test orthe Mann Whitney U ranking test. Nominal parameters were compared using the Chi-square test or Fisher exact test. All tests were two-tailed, with a 5 % significance level. Data wasanalyzed using the SPSS software (IBM®SPSS® version 27).

2.5. Helsinki Approval

The study was approved by the Wolfson Medical Central Helsinki Committee (WOMC-055-21).

3. Results

3.1. Population

A total of 20 children aged 2.1–17.2 years (mean 9.57 ± 1.01), including 12 females (60 %), underwent home video EEG, and was compared to a control group of 20 children, aged 1.4–18.5 years(mean 10.2 ± 1.21)who underwent in-hospitalprocedure (Table 2).

The home EEG group had higher prevalence of children with intellectual disability and/or autism compared to the in-hospital EEG control group:12 patients (60 %) vs.5 (25 %) ($p < 0.05^*$, Fisher exact test) (Table 2). Similarly, patients with developmental and epileptic encephalopathy were overrepresented in the ambulatory group (7 i.e.,35 % vs. 0), while patients withself-limited childhood epilepsy were overrepresentedin the in-hospital group (5 i.e., 25 % vs 0) ($p < 0.05^*$, Chi square) (Table 2).

The primary reasons for referral in the home EEG group wereseizure localization and classification in 11 patients (55 %), paroxysmal event classification in 5 (25 %) and quantification of sleep epileptic activity in 4(20 %), which were similar to the control group (40 %, 40 % and 20 % respectively, NS, Chi square) (Table 2). Staring spells were the reason for referral in 6 patients (30 %) in the ambulatory group: focal awareness impaired seizure-2 (10 %), absence seizures-2 (10 %), nonepileptic-2 (10 %). In the in-hospitalgroup, 10 patients (50 %) were referred due to staring spells: focal awareness impaired seizures −5 (25 %), absence

Table 2
Demographic and clinicalcharacteristics of the two groups.

	Ambulatory	In-hospital	Significance
Age (years)	9.57 ± 1.01	10.2 ± 1.21	$p > 0.05$(T test)
Mean $\pm$ SD[range]	[2.1–17.2]	[1.4–18.5]	
Gender			$p > 0.05$(Chi square)
• Male (percentage)	8 (40 %)	10 (50 %)	
• Female(percentage)	12 (60 %)	10 (50 %)	
Intellectual disability and/or autism	12 (60 %)	5 (25 %)	$P < 0.05^*$(Fisher Exact test)
Diagnosis			$P < 0.05^*$(Chi square)
No epilepsy	2(10 %)	4(20 %)	
Electrical status epilepticus during slow wave sleep	3 (15 %)	1(5 %)	
Developmental and epileptic encephalopathy	7 (35 %)	0	
Focal onset epilepsy	5 (25 %)	7 (35 %)	
Self-limited childhood epilepsy	0	5 (25 %)	
Idiopathic generalized epilepsy	3 (15 %)	3 (15 %)	
Reason for referral			$p > 0.05$ (Chi square)
Seizure localization/classification	11 (55 %)	8 (40 %)	
• Motor (focal or generalized onset)seizures	5(25 %)	2 (10 %)	
• Cluster seizures	2 (10 %)	0	
• Focal awareness impaired seizures	2 (10 %)	5 (25 %)	
• Absence seizures	2 (10 %)	1(5 %)	
Paroxysmal event classification	5(25 %)	8(40 %)	
• Nonepileptic staring	2(10 %)	4(20 %)	
• Myoclonus	2 (10 %)	0	
• Nocturnal events	1 (5 %)	2(10 %)	
• Psychogenicnonepileptic seizures	0	2 (10 %)	
Sleep epileptic activity quantification	4 (20 %)	4 (20 %)	

seizures-1 (1 %), nonepileptic-4(20 %) (NS, Chi square). Classification of major motor events was the referral in 7 patients in the ambulatory group (35 %):focal to bilateral tonic clonic or generalized tonic clonicseizures-5 (25 %), cluster seizures-2(10 %). In the in-hospitalgroup 4(20 %)were referred for major motor events: focal to bilateral tonic clonic or generalized tonic clonic seizures −2 (10 %), psychogenic non epileptic seizures-2(10 %) (NS, Chi square). Four patients in each group (20 %) were referred for quantification of epileptiform activity to rule outESES.

3.2. 3.2outcome measures

The quality of the EEG recording in the ambulatory setting wassatisfactory, with a mean score of 4.05 ± 1.66. Overall, 16 recordings (80 %) were informative, with 14 recordings (70 %) receiving the highest score: 5 (Fig. 1a). Three recordings experienced major technical issues resulting in non-informative tests due to battery detachment, while two had electrode disconnections (Fig. 1). In contrast, there were no non-informative tests in the in-hospital setting, but two cases had electrode detachments.Unfortunately, the EEG technician was not alerted by the nursing staff about the electrode malfunctioning, and the detachments were not corrected. Another technical problem which we encountered in the in-house recording was a 50 cycle artefact, which lowered the quality scoring in 6 patients. Overall, the quality of EEG recording was higher in the ambulatory group (median 5 [IQR 3.25–5] vs 4[IQR 3–4], $p < 0.05*$, Mann-Whitney U ranking test) (Fig. 1a).

Video recordings were informative in 15 cases (75 %), with a mean score of 3.05 ± 1.43, but only 3 recordings (15 %) achieved the highest quality score of 5 (Fig. 1b). In four patients (20 %), the video recording was non-informative, with three cases experiencing battery detachment issues. In the fourth case, the infrared light was off during a nocturnal ictal event, rendering it invisible. In one additional recording, only partial visibility of body parts during the event was possible. Furthermore, in 7 recordings (35 %), there were brief periods without synchronization between the EEG and video recordings, but the recordings were informative. Overall, the quality of video recording was lower in the ambulatory group (median 3[IQR 2.25–4] vs 5[IQR4-5], $p < 0.01**$, Mann-Whitney U ranking test) (Fig. 1b).Eight patients(40 %) had their habitual events recorded during home procedure, while 9 patients (45 %) had habitual events during in-house recording (NS, Chi square).

4. Discussion

4.1 During the COVID-19 pandemic, as epilepsy monitoring units faced a decrease in activity, home video-EEG monitoring emerged as an alternative option for long-term EEG monitoring,as recommended by the International League Against Epilepsy (ILAE) and the International Federation of Clinical Neurophysiology [7].Additionally, ambulatory video-EEG monitoring holds significant economic advantages, with lower costs compared to inpatient settings [8]. In the adult population it has proven useful tool for diagnosingnon-urgent epileptic events, capturingnon-epileptic events, assessing epileptic activity burden,and evaluating treatment response in the natural patients' environment [2–4,9,10].With appropriate selection of patients, the diagnostic yield for home video-EEGin pediatric patientsmay be similar to inpatient admissions, around 70 % [10–13].

In this prospective pilot study, we explored the feasibility of home video-EEG telemetry in a pediatric population referred to the Pediatric Neurology Unit for various indications. The key finding of our study was the overrepresentation of children with intellectual disability and/or autism, as well as children with developmental and epileptic encephalopathy in the ambulatory EEG group compared to the in-hospital group (Table 2). The assignment to each group was not random, but ratherwas subject to the parents' discretion,
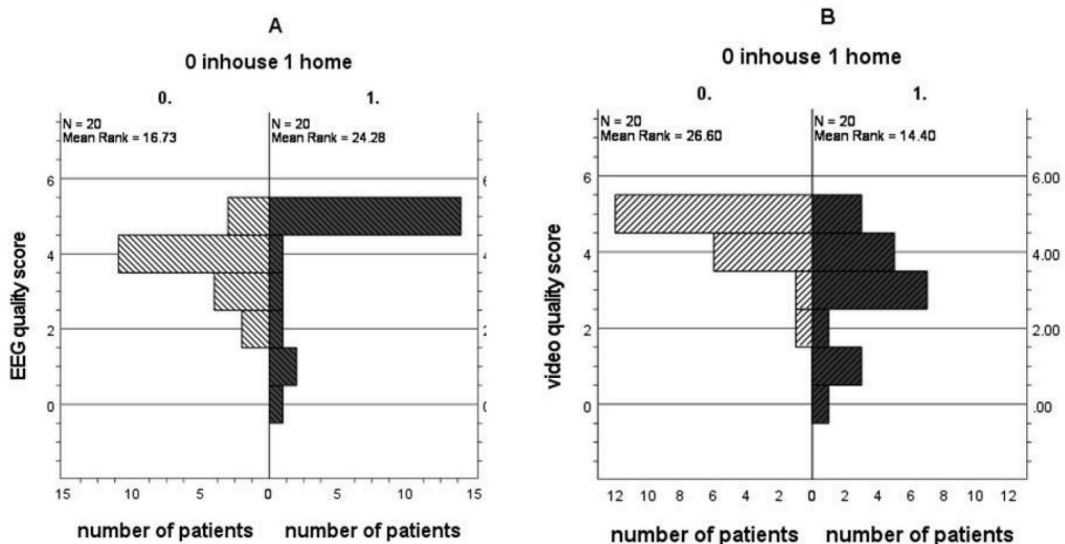

Fig. 1. EEG and video recording quality score.

suggesting that ambulatory video-EEG monitoring may be a preferable option for children with neurodevelopmental disorders, who might experience added stress and discomfort during hospitalization.

Home video-EEG might be the ideal tool for differentiating between epileptic and non-epileptic paroxysmal eventsin children. Previous studies by Alix et al., 2014(11), Syed et al., 2019(10), DiGiovine et al., 2022(12) indicated that the majority of pediatric patients were referred for classification of non-epileptic paroxysmal events. Surprisingly, in our study, the primary reason for referral to home video-EEG was classification and localization of seizures, similarly to the in-hospital group (Table 2). These results might be explained by the bias in selection of the groups, as caregivers of children with special needs choose to perform the home procedure. It should be stressed that in our clinic, the short 24-h video EEG recordings were not intended for surgical evaluation. Longer recordings (3–10 days) [9,10,14]in combination with seizure forecast algorithms [15] and improved event capture [16] might be needed to address these clinical needs.

For the intended purpose of non-surgical evaluations, the yield of home EEG was high in our study, with 75 % percents of the tests being informative (Fig. 1), consistent with other reported studies [10,12,13]. However, while the quality of the EEG recording during ambulatory monitoring was higher than the in-hospitalrecordings:median 5 [IQR 3.25–5] vs 4[IQR 3–4] ($p < 0.05$*, Mann-Whitney U ranking test) (Fig. 1a). The quality of the video recording was significantly lower: median 3[IQR 2.25–4] vs 5[IQR4-5] ($p < 0.01$**, Mann-Whitney U ranking test) (Fig. 1b). This discrepancy could be attributed to equipment failure, such as detachment of the battery or faulty camera synchronization, issues that were related to the novelty of the equipment and were subsequentlycorrected. Other technical shortcomingsrelated to events or body partsvisibility might be overcome by better caregiver training onwide-angle camera positioning and infrared button usage for night recording [6,12,13,16].

The safety of the procedure in young infants needs further investigation, asthere iscurrently no minimum age recommendation. While some studies enrolled children over three years of age (Alix et al. , 2014) [11] or seven years of age (Syed et al., 2019) [10], our youngest participant was two years of age and children as young as one year of age have been reported (Carlson et al., 2018) [13].

5. Conclusions

Despite limitations in video recording quality, our study demonstrates that home video-EEG monitoring is a feasible and valuable option for pediatric EEG monitoring, especially for children with special needs. By allowing patients to remain in their natural environment, ambulatory monitoring reduces the burden on the child and their family, potentially leading to improved compliance and acceptance of the procedure.Further advancements in technology and improvements in ambulatory video-EEG systems may address some of the current limitations and enhance the overall quality of ambulatory monitoring.

Declaration of generative AI and AI assisted technologies in the writing process

Statement During the preparation of this work the authors used Chat GPT TOOL in order to proofread the documented edit style to a native English level. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Data availability statement

Data is included in article supplementary material.

CRediT authorship contribution statement

Yael Michaeli: Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Lubov Blumkin:** Investigation. **Mordekhay Medvedovsky:** Software, Investigation. **Ilan Dalal:** Investigation. **Andreea Nissenkorn:** Writing – review & editing, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

Dr. Mordekhay Medvefovsky is involved in startup company VIRDA that develops home-video-EEG system.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e35108.

References

[1] J. Askamp, M.J. van Putten, Mobile EEG in epilepsy, Int. J. Psychophysiol. 91 (1) (2014) 30–35.

[2] S. Jamal Omidi, J.P. Hampson, S.D. Lhatoo, Long-term home video EEG for recording clinical events, J. Clin. Neurophysiol. : official publication of the American Electroencephalographic Society 38 (2) (2021) 92–100.

[3] A. Kaundal, V. Hegde, H. Khan, H. Allroggen, Home video EEG telemetry, Practical Neurol. 21 (3) (2021) 212–215.

[4] F. Brunnhuber, J. Slater, S. Goyal, D. Amin, G. Thorvardsson, D.R. Freestone, et al., Past, Present and Future of Home video-electroencephalographic telemetry: a review of the development of in-home video-electroencephalographic recordings, Epilepsia 61 (Suppl 1) (2020) S3–s10.

[5] F. Brunnhuber, D. Amin, Y. Nguyen, S. Goyal, M.P. Richardson, Development, evaluation and implementation of video-EEG telemetry at home, Seizure : the journal of the British Epilepsy Association. 23 (5) (2014) 338–343.

[6] S. Biswas, R. Luz, F. Brunnhuber, Home Video Telemetry vs inpatient telemetry: a comparative study looking at video quality, Clin Neurophysiol Pract 1 (2016) 38–40.

[7] S. Beniczky, A. Husain, A. Ikeda, H. Alabri, J. Helen Cross, J. Wilmshurst, et al., Importance of access to epilepsy monitoring units during the COVID-19 pandemic: consensus statement of the international League against epilepsy and the international federation of clinical Neurophysiology, Clin. Neurophysiol. : official journal of the International Federation of Clinical Neurophysiology 132 (9) (2021) 2248–2250.

[8] J.D. Slater, M. Eaddy, C.M. Butts, I. Meltser, S. Murty, The real-world economic impact of home-based video electroencephalography: the payer perspective, J. Med. Econ. 22 (10) (2019) 1030–1040.

[9] C.T. Primiani, A. Rivera-Cruz, P. Trudeau, L. Sullivan, S. MacIver, S.R. Benbadis, The yield of ambulatory EEG-video monitoring, Clin. EEG Neurosci. : official journal of the EEG and Clinical Neuroscience Society (ENCS). 52 (4) (2021) 274–279.

[10] T.U. Syed, W.C. LaFrance Jr., T. Loddenkemper, S. Benbadis, J.D. Slater, R. El-Atrache, et al., Outcome of ambulatory video-EEG monitoring in a ~10,000 patient nationwide cohort, Seizure : the journal of the British Epilepsy Association 66 (2019) 104–111.

[11] J.J. Alix, R.H. Kandler, S.R. Mordekar, The value of long term EEG monitoring in children: a comparison of ambulatory EEG and video telemetry, Seizure : the journal of the British Epilepsy Association. 23 (8) (2014) 662–665.

[12] M.P. DiGiovine, S.L. Massey, D. LaFalce, L. Vala, L. Allen-Napoli, B.L. Banwell, et al., Video ambulatory EEG in children: a quality improvement study, J. Clin. Neurophysiol. : official publication of the American Electroencephalographic Society 39 (4) (2022) 271–275.

[13] S. Carlson, R.H. Kandler, D. Moorhouse, A. Ponnusamy, S.R. Mordekar, J.J.P. Alix, Home video telemetry in children: a comparison to inpatient video telemetry, Seizure : the journal of the British Epilepsy Association 61 (2018) 209–213.

[14] V. Wong, T. Hannon, K.M. Fernandes, D.R. Freestone, M.J. Cook, E.S. Nurse, Ambulatory video EEG extended to 10 days: a retrospective review of a large database of ictal events, Clin. Neurophysiol. : official journal of the International Federation of Clinical Neurophysiology 153 (2023) 177–186.

[15] W. Xiong, R.E. Stirling, D.E. Payne, E.S. Nurse, T. Kameneva, M.J. Cook, et al., Forecasting seizure likelihood from cycles of self-reported events and heart rate: a prospective pilot study, EBioMedicine 93 (2023) 104656.

[16] E.S. Nurse, T. Perera, T. Hannon, V. Wong, K.M. Fernandes, M.J. Cook, Rates of event capture of home video EEG, Clin. Neurophysiol. : official journal of the International Federation of Clinical Neurophysiology 149 (2023) 12–17.