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Original Article

Novel Smartphone-Based Screening Tool for Absence Seizures in Pediatric Settings: A Comparative Study With Video EEG

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ABSTRACT

Background: Staring spells, a common chief complaint in pediatrics, lead to both over-referral and under-referral to neurologists, creating significant challenges in clinical care. Children with nonepileptic staring episodes are frequently referred unnecessarily to neurology, while children with Childhood Absence Epilepsy are commonly misdiagnosed with disorders such as attention-deficit/hyperactivity disorder (ADHD). Hyperventilation (HV) has long been used as a neurobehavioral tool to provoke and diagnose absence seizures in children with suspected Childhood Absence Epilepsy. We evaluated the Eysz HV Recorder, a smartphone-based tool that guides children through HV while capturing video, as a screening tool for absence seizures.
Methods: Sixty participants underwent HV using the HV Recorder during electroencephalography observation. Two independent, blinded panels of three epileptologists each reviewed the data as follows: one panel reviewed the video electroencephalography (vEEG) and the other reviewed the HV Recorder video. We assessed the HV Recorder reviewers' ability to detect seizures compared to the vEEG reviews.
Results: HV Recorder reviewers had 100% sensitivity and 91% specificity for identifying absence seizing patients with seizures $\geq$7 s. Individual seizures were detected with 96% sensitivity for seizures $\geq$7s and 86% across seizures of all lengths. Agreement levels were similar between epileptologists reviewing the vEEG and the HV Recorder video (vEEG-vEEG: 90%, HV-HV: 87%, HV-vEEG: 82%). Reviewers reported they could clearly identify clinical events from the HV Recorder video more often than the vEEG video.
Conclusions: The Eysz HV Recorder is an accurate tool with high sensitivity and specificity for identifying absence seizures, which could aid clinicians in differentiating epileptic from nonepileptic staring spells.

Introduction

Staring spells, a common chief complaint in pediatrics, frequently result in both over-referral and under-referral to neurologists, posing significant challenges for clinical care. The difficulty is in differentiating between epileptic and nonepileptic staring spells where a clear history may be difficult to obtain.[1-3] Children with nonepileptic staring episodes are often referred unnecessarily to pediatric neurology, contributing to increasing length of specialist waitlists and increasing health care costs.[1-3]

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Ethics approval: All procedures in this research were performed in compliance with relevant laws and institutional guidelines. This study was approved by the Institutional Review Board of Cincinnati Children's Hospital Medical Center; IRB-ID: 2023-0050; February 28, 2023.

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Conversely, children with true absence seizures—commonly associated with Childhood Absence Epilepsy (CAE),[4-6] a generalized epilepsy syndrome presenting between ages 4 and 10 years—are frequently misdiagnosed with behavioral or attention disorders such as attention-deficit/hyperactivity disorder (ADHD), delaying appropriate treatment.[7] This diagnostic imbalance reflects the difficulty of accurately identifying absence seizures in routine clinical settings and is compounded by limited access to pediatric neurology and video electroencephalography (vEEG) monitoring. The challenge of accurately identifying absence seizures persists even after diagnosis, as neurologists often find it difficult to determine remission or treatment response based solely on patient history.

Hyperventilation (HV) has long been used by neurologists to provoke absence seizures in children with suspected CAE.[3,8-10] HV is typically performed in conjunction with electroencephalography (EEG), and so the diagnostic accuracy of identifying HV-provoked seizures through clinical observation alone, without EEG, remains unclear. Additionally, procedures for HV vary from institution to institution, and the lack of standardization makes the effectiveness of HV difficult to assess. The diagnostic accuracy of HV has never been rigorously validated in a device-assisted format. To address this gap, we evaluated the Eysz HV Recorder, a smartphone-based tool that guides children through HV while capturing video. We hypothesized that epileptologists reviewing these recordings could identify absence seizures with accuracy comparable to vEEG, providing a scalable, accessible, and standardized solution to improve early diagnosis and reduce misclassification of staring spells in children.

Materials and Methods

Participants

The study was conducted at Cincinnati Children's Hospital after approval by the institutional review board. Participants were children aged 4-12 years referred for EEG evaluation for suspected absence seizures with or without a prior diagnosis of CAE. Criteria for inclusion in the study were as follows: (1) no developmental disabilities or medical conditions that would prevent cooperation with the study protocol, including vEEG and HV, (2) no known history of generalized tonic-clonic seizures provoked by HV; and (3) no pre-existing medical conditions for which HV is contraindicated (subarachnoid hemorrhage, sickle cell anemia, recent cerebrovascular accident or myocardial infarction, significant cardiopulmonary disease, active asthma, known aneurysm or moyamoya disease, and advanced pregnancy). A total of 65 participants were enrolled in the study. The first 5 participants were excluded from the study due to protocol deviations—the participants were recorded in supine position rather than sitting up with a clear view of the face. Sixty participants were included in the study. All participants gave informed consent before participating in the study. For children aged 10 years of age and under, parental consent was received and children gave verbal assent to participate in the study. Children over 10 years of age gave written consent. The Table below shows participant demographic information.

TABLE.
Study Participant Demographic Information

Demographic Category	Seizing Participants	Nonseizing Participants
Sample size	15	45
Absence seizures $\geq$ 7 s	11	-
All absence seizures < 7 s	4	-
Gender	9 females; 6 males	21 females; 24 males
Age	Mean: 9.73, S.D.: 2.48	Mean: 9.42, S.D.: 2.12
Ethnicity		
Hispanic/Latino	0%	2.2%
Non-Hispanic/Latino	100%	97.8%
Race		
American Indian or Alaskan Native	0%	2.2%
Asian	0%	0%
Black or African American	6.7%	11.1%
Native Hawaiian or Pacific Islander	0%	0%
White	93.3%	86.7%

Abbreviation:
vEEG = Video electroencephalography
"Seizing Participants" refers to any participants where a seizure was recorded on the vEEG during the study as determined by majority agreement of the three vEEG reviewers.

Study procedure

Participants underwent guided HV using the Eysz HV Recorder smartphone application in a clinical setting concurrent with vEEG. Electrode placement and standard EEG procedures followed the site's established clinical EEG protocols. Participants were seated on an elevated gurney, with their back and head elevated to mimic a sitting position. A mobile phone preloaded with the Eysz HV Recorder was positioned on a tripod 30 cm in front of the participant. The Eysz HV Recorder guided participants through HV while recording audio and video from the phone's front facing camera (Fig 1). First, the child watched an instructional video on the phone. Then the positioning was confirmed as follows: a green border on the screen confirmed proper face positioning; if the face was not detected, the border turned red to prompt adjustment. Once correctly aligned, the HV recording began. Facial tracking continued throughout the session, alerting the user if the face moved out of frame.

The HV procedure lasted for 5 minutes. There was one minute of baseline in which a cartoon video was displayed on the phone screen, followed by 3 minutes of gamified active HV, and finally a one-min cooldown period in which another cartoon was shown. The 3-minute HV section began with a countdown to prepare the participant to begin blowing. An indicator (an animated image of a cloud) guided the participant when to blow, appearing and disappearing at a rate of 22 beats per minute, to achieve an optimal breath rate of 20-24 breaths per minute.

During the entire 5-minute session, the camera function of the smartphone recorded video of the face at 30 fps and 720 $\times$ 1080 resolution, along with audio at 48 kHz. Following the session, the recording was automatically uploaded to a secure cloud-based data repository. Age, race, ethnicity, clinical history, medication history, and current medications were collected via caregiver report for all participants. Height and weight were also recorded.

vEEG and HV recorder video reviews

Three board-certified epileptologists from Cincinnati Children's reviewed and annotated the vEEG recording that coincided with the use of the Eysz HV Recorder application. Each reviewer independently marked each EEG for the presence of seizures, reporting the start and stop time of each seizure. The vEEG reviewers had no access to the Eysz HV Recorder HV video recordings.

An independent set of three board-certified epileptologists from the Epilepsy Study Consortium reviewed the HV videos recorded using the Eysz HV Recorder. Reviewers accessed the HV recordings securely using the Eysz HV Recorder portal. Each reviewer was trained on the use of the Eysz HV Recorder portal

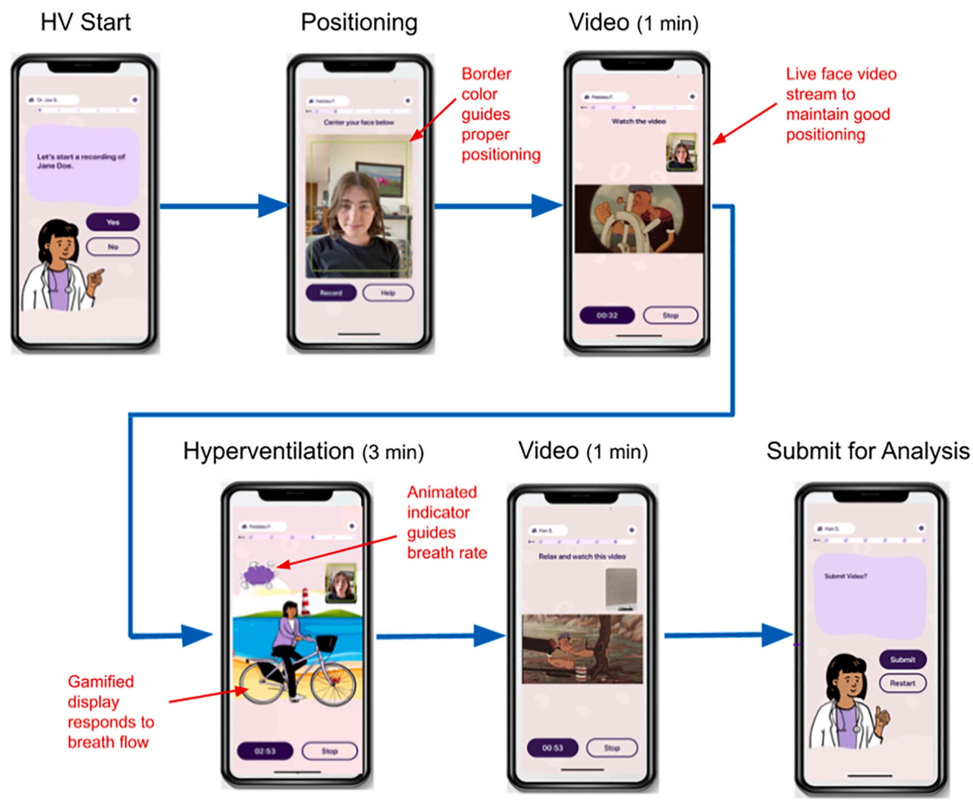

FIGURE 1. Eysz HV Recorder. The Eysz HV Recorder is a smartphone application that guides a patient through hyperventilation while recording high-quality video of the face for clinical review. An animated indicator guides breathing to facilitate optimal breath rate, while a dynamic display responds to breath flow, gamifying the experience and providing continuous feedback on HV effort. The procedure consists of one minute of baseline, 3 minutes of active HV, and one minute of cooldown, with a cartoon video displayed during baseline and cooldown. Afterward, the video is uploaded to a secure portal where it is reviewed by expert clinicians. HV, hyperventilation. The color version of this figure is available in the online edition.

and identification of absence seizures. Reviewers marked the presence of seizures, periods when the video was unreadable, and the start and stop time of each seizure. Reviewers were blind to each other's reviews and had no access to the vEEG recording.

All reviewers marked the semiology associated with each seizure, their confidence in determining seizure presence, and the participant's HV effort. Reviewers also assessed video quality, indicating whether they could see the participant's face clearly enough to identify clinical events, and if not, to specify the reason. In addition to annotating seizure times during HV, each of the vEEG reviewers also marked whether the participant had any seizures during the observation outside of the HV period.

All reviewers have no financial interests or competing stakes in the Eysz HV Recorder.

Analysis methods

The goal of our analysis was to evaluate the Eysz HV Recorder smartphone application's effectiveness as a screening and monitoring tool for CAE. Our primary analyses compared the performance of trained epileptologists reviewing Eysz HV Recorder videos to the reviews of vEEG recordings (the gold standard). We first evaluated the Eysz HV Recorder application's sensitivity and specificity for detecting participants that experience seizures. This analysis is the most clinically relevant for assessing the device's efficacy, as it aligns with its intended use for screening and monitoring patient seizures. We also looked at the detection of individual seizures since many participants may have more than one seizure, and quantification of seizures may be useful for other clinical uses.

Following the clinical reference standard set by the FDA for defining seizures in clinical studies, the presence of seizures was determined by majority agreement of the three vEEG reviewers. Because reviewers may not agree about the exact start and stop time of seizures, agreement was defined as at least 50% of the seizure time overlapping between the reviewers. Similarly, we used majority agreement among the three HV Recorder reviewers to evaluate the HV Recorder's performance for our main analyses. We also investigated the sensitivity and specificity of individual HV Recorder reviewers to better understand the consistency of reviewers and investigate the performance of using the application with only a single reviewer in future applications.

Each seizure's length was also defined by majority agreement of the three vEEG reviewers. In cases where no two reviewers agreed on the length, length was determined by the mean of the three reviews. In the CAE study by Glauser et al.,[11] clinically apparent seizures had a median duration of 10 seconds, compared with 5 seconds for nonclinical seizures. Based on these observations, a 7-second threshold was selected to guide analyses, as HV represents an active task in which clinical events are more likely to be recognized than during passive observation. We focused our main analyses on seizures ≥7 seconds but also reported results with all seizures included.

We analyzed agreement between individual reviewers of both sources to better understand the reliability of each and heterogeneity of different experts. Understanding agreement between vEEG reviewers also gives us an upper limit of what we should

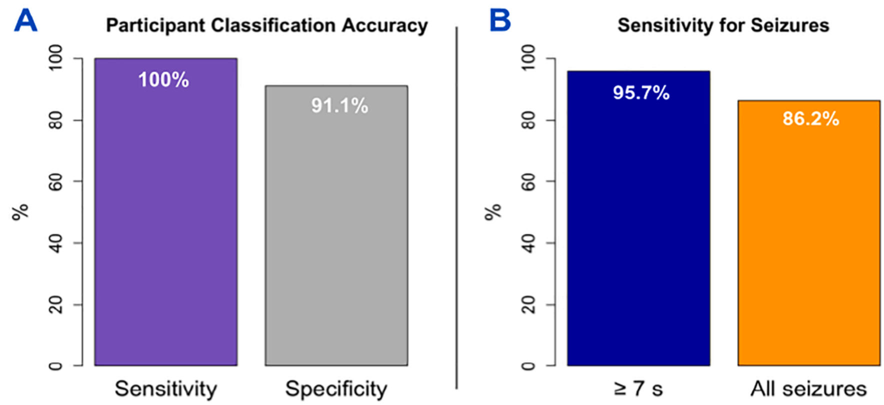

FIGURE 2. Eysz HV Recorder efficacy. (A) Sensitivity and specificity for classifying participants as actively seizing versus seizure free for participants with seizures ≥ 7s. (B) Sensitivity for identifying individual seizures. The color version of this figure is available in the online edition.

expect for accuracy from the HV Recorder reviewers. For example, if vEEG reviewers only agreed 80% of the time, we should not expect HV Recorder reviews to have a sensitivity above 80%, since the underlying labels that are used as the ground truth value to compare against are themselves subject to individual variance of opinion. For agreement analysis, we took each instance of a vEEG reviewer marking a seizure during a recording and looked at whether each of the other reviewers (both vEEG and HV Recorder) marked the same time period as a seizure. In this way, we assessed agreement proportions between each pair of reviewers and then summarized them across 3 categories (vEEG-vEEG, HV-HV, vEEG-HV).

Additionally, we investigated seizures occurring during the vEEG recording outside of the HV portion. With this information, we can calculate the sensitivity of HV (using the Eysz HV Recorder) combined with EEG since it gives us the proportion of seizing participants that responded to the HV procedure.

Finally, we looked at the reviewers' responses when they assessed each recording for whether they could see the participant's face clearly enough to identify clinical events and compared between the vEEG video and the HV Recorder smartphone video.

Results

Seizure characteristics

Fifteen participants had seizures during the 5-minute HV recording sessions, and across all seizing participants a total of 29 absence seizures occurred. All reported seizures were marked as typical absence seizures by the vEEG reviewers. One vEEG reviewer reported a nonabsence seizure in one participant, but the other two vEEG reviewers did not report any seizures for that participant. One of the HV Recorder reviewers also reported a nonabsence seizure in the same participant at the same time with a similar description (i.e., eyelid myoclonia). Across all participants in the study, no other nonabsence seizures were reported and no adverse events were reported. These outcomes align with previous research on the relative safety of HV as a neurobehavioral technique.[12]

Mean absence seizure length was 9.91 seconds (S.D. = 5.56), and median length was 8.0 seconds. The shortest seizure reported was 4 seconds, while the longest was 30 seconds. Most seizing participants had only a single seizure (N = 9) during the recording, while the largest number of seizures recorded from a single participant during the HV session was 6. Seven participants also had seizures outside of the HV Recorder session during the vEEG recordings. Five of these participants seized during HV, while two did not.

There were four participants in our study whose longest seizure during HV was <7 seconds long. Each of these participants had only a single seizure and all were patients previously diagnosed with CAE and were taking antiseizure medications (ASMs). None of these participants had seizures during the observation outside of the HV session.

Participant classification performance

Across all participants, sensitivity was 80% and specificity was 91.1%. For participants with seizures ≥7 seconds, sensitivity in classifying participants as having absence seizures was 100% (Fig 2A). Individual reviewers averaged 97.0% sensitivity for classifying participants with seizures ≥7 seconds. Two reviewers had 100% sensitivity, while the other missed only a single participant. Across all participants (with seizures of any length), mean sensitivity was 80.0% (S.D. = 6.7%). Mean specificity across reviewers was 88.1%.

Seizure detection performance

Sensitivity for detecting individual seizures was 95.7% for seizures ≥7 seconds and 86.2% across all seizures based on majority agreement of the three reviewers (Fig 2B). For individual reviewers, mean sensitivity for detecting individual seizures was 89.9% (S.D. = 2.5%) for seizures ≥7 seconds, and 81.6% (S.D. = 4.0%) for seizures of any length.

Overall, these results show a very high performance of experts using the Eysz HV Recorder application to both identify seizing patients and to detect individual seizures. Additionally, they suggest that a single reviewer may be sufficient for clinical use rather than relying on majority agreement of 3 reviewers.

Agreement between reviewers

Overall, a vEEG reviewer tended to agree with any other vEEG reviewer 90.0% (S.D. = 6.3%) of the time when analyzed across all reviewers (Fig 3). Proportion agreement was 97.2% for seizures ≥7 seconds long and 61.9% for seizures <7 seconds. HV Recorder video readers agreed with each other 87.1% (S.D. = 0) of the time (88.9% for seizures ≥7 seconds and 81.0% for seizures <7 seconds). HV Recorder video readers agreed with the vEEG readers 82.3% (S.D. = 3.5%) of the time (88.9% for seizures ≥7 seconds and 57.1% for seizures <7 seconds).

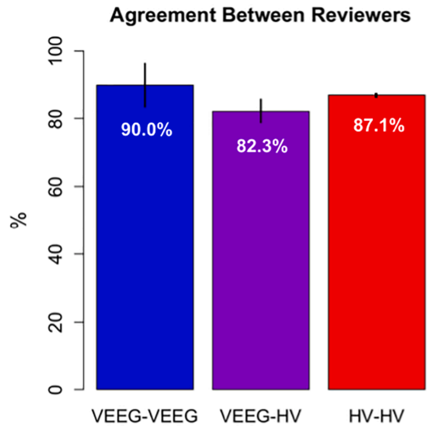

FIGURE 3. Agreement between reviewers. Agreement levels were high in both groups and were similar between the vEEG and HV Recorder reviewers, suggesting similar levels of reliability, and little or no systematic bias in the HV Recorder reviews. HV, hyperventilation; vEEG, video electroencephalography. The color version of this figure is available in the online edition.

This shows that agreement levels were similar between reviewers regardless of source. Given that vEEG reviewers agree with each other 90% of the time (and therefore we would expect a single vEEG reviewer's sensitivity to about 90% on average), the sensitivity reported above for HV Recorder reviewers appears to be high.

Seizures outside of HV

As in other analyses, we used the majority agreement of the three vEEG reviewers as the gold standard for determining whether seizures occurred outside of HV. Altogether, 7 participants were marked as having seizures outside of HV, 5 of whom also had an absence seizure during the HV session. There were 2 participants that had seizures outside of HV but did not seize during the HV session. Therefore, the HV procedure provoked seizures in 15 out of 17 participants (88.2%) who had seizures at any time during the study, either during HV or outside of HV. This result matches previous literature indicating that HV provokes seizures in approximately 90% of individuals with active seizures.[10,13,14] Both participants who had seizures outside of (but not during) HV had a known diagnosis of CAE prior to the study and were taking ASMs.

Face Visibility in vEEG and HV Recorder Videos

Fourteen (23.3%) videos were marked not visible by at least one of the three vEEG readers. Two videos were marked not clearly visible by two reviewers; all others were marked not visible by only one reviewer. In contrast, all HV Recorder readers marked all videos as clearly visible.

Discussion

This study demonstrates that absence seizures provoked by HV, a widely adopted clinical technique, can be accurately identified from smartphone video recordings with performance comparable to in-clinic routine or vEEG, which is the current gold standard.[2,8,10,15,16] Using the Eysz HV Recorder, epileptologists achieved high sensitivity and specificity for both participant-level classification and individual seizure detection, particularly for seizures lasting ≥7 seconds. Agreement among HV Recorder reviewers was comparable to that of vEEG reviewers, suggesting that this tool provides reliable clinical information even without direct EEG correlation. This work validates HV as a diagnostic method for absence seizures in a standardized, reproducible, and device-assisted context.

This work has significant clinical and economic implications. Short staring spells without significant motor features or a postictal state are a common reason for pediatric neurology referrals, yet many of these children are ultimately diagnosed with nonepileptic events.[17] While other seizure types include staring, they typically present with additional clinical features that warrant direct specialist evaluation regardless.[18] For isolated staring spells, however, it remains difficult to rule out absence seizures without an EEG. This diagnostic inefficiency contributes to unnecessary referrals, delayed care, and increased health care costs. In the United States, a routine EEG costs approximately $200-$700, while long-term vEEG monitoring can exceed several thousand dollars per evaluation. If implementation of the Eysz HV Recorder could safely prevent even 30% of referrals for nonepileptic staring spells (at less than 10% the average cost of an EEG), the potential cost savings to the health care system would be substantial. To illustrate how this technology could be integrated into routine clinical practice, consider a common primary care scenario: a child is being evaluated for 'zoning out' episodes alongside symptoms consistent with ADHD. Often, the clinical description of the events provided by caregivers is vague, leaving the primary care provider (PCP) with a low-to-moderate pretest probability of epilepsy. Rather than immediately initiating an empirical neurology referral—which contributes to long specialist waitlists and increased health care costs—the PCP could utilize the Eysz HV Recorder as a screening tool. The patient completes the brief, guided hyperventilation test in the primary care clinic, and the high-resolution video is securely uploaded to a cloud-based portal. A remote pediatric epileptologist can then asynchronously review the footage to identify any clinical events. This asynchronous coordination allows the PCP to receive expert guidance on whether to confidently proceed with behavioral management or to facilitate a targeted, high-yield referral to neurology equipped with video evidence.

In the current study, the Eysz HV Recorder demonstrated a low false-positive rate, indicating its ability to reduce unnecessary referrals while maintaining high sensitivity for detecting absence seizures. Conversely, children with CAE often experience delayed or missed diagnoses due to limited access to appropriate testing, frequently resulting in misdiagnoses such as ADHD or behavioral disorders.[7,19] By enabling accurate absence seizure identification outside of the EEG laboratory, the Eysz HV Recorder offers a practical solution to streamline triage, reduce diagnostic delays, and expand access to timely care. Integrating this tool into frontline pediatric workflows could improve efficiency, optimize resource utilization, and enhance clinical outcomes.

Our findings reinforce the well-established role of HV as a reliable diagnostic maneuver, consistent with prior studies showing that HV provokes seizures in approximately 90% of children with active absence epilepsy.[10,13,14] Importantly, reviewers reported that the Eysz HV Recorder provided a sufficiently clear facial view to identify clinical events in all participants, whereas 23% of conventional vEEG recordings were rated as not sufficiently clear by at least one reviewer. Because absence seizures are brief and subtle, a clear view of the face is critical for accurate detection—underscoring why vEEG, rather than EEG alone without video, is considered the gold standard for diagnosing absence seizures.[20]

Although this study employed a standardized tripod setup to ensure data integrity, the Eysz HV Recorder is designed for flexible, real-world use. Its built-in positioning guide and high-resolution video capture help overcome common quality and positioning challenges that often limit the diagnostic value of vEEG recordings. By standardizing both the HV process and video quality, the Eysz HV Recorder enhances the reliability of seizure detection and supports use alongside standard EEG, which remains essential for definitive electrophysiological diagnosis and seizure classification.

Several limitations of this study should be acknowledged. First, this was a single-site study with a modest sample size and a limited number of seizures captured during the HV protocol. Although performance metrics were robust, larger multicenter studies are needed to confirm the generalizability of these findings across a broader population of children with varying clinical backgrounds. Second, the potential for spectrum bias should be considered, as all participants were referred for or currently receiving neurological care. The high specificity observed in this cohort may not fully translate to primary care settings, where the prevalence of epilepsy is lower. Accordingly, the positive and negative predictive values of the Eysz HV Recorder should be evaluated in future studies enrolling a true screening population. This research constitutes the first step in validating a digital tool that standardizes and facilitates the administration of a widely used neurological test, opening up its potential to be used in new clinical settings, but its applicability to those settings still requires further testing.

This study primarily validated the technical accuracy of video-based seizure identification, demonstrating improved detection performance for seizures lasting $\geq$7 seconds relative to shorter events. The few shorter seizures occurred in participants already receiving ASMs, which may reduce seizure duration and attenuate observable clinical features. Extending or repeating the HV procedure may help mitigate potential false negatives in treated children with known CAE. In our sample, no untreated children with seizures were missed, though this finding should be interpreted cautiously given the limited sample size. Future studies will formally evaluate the health-economic impact of deploying the Eysz HV Recorder to triage children awaiting neurology consultation, quantifying its potential to improve access, accelerate diagnosis, and reduce system-wide costs. By enabling earlier identification and treatment initiation, this approach has the potential to shorten time to seizure freedom and fundamentally improve the efficiency of pediatric epilepsy care.

In treatment monitoring, vEEGs are typically repeated after initiation of ASMs to assess treatment efficacy. The Eysz HV Recorder's portable, smartphone-based design offers strong potential for in-home monitoring, which will be explored in future studies. If comparable diagnostic accuracy can be achieved outside of the clinic, home use of the Eysz HV Recorder could substantially reduce health care costs associated with repeat vEEG admissions while enabling more timely and frequent assessments of seizure control. For example, the procedure could be repeated weekly during ASM titration, allowing clinicians to make evidence-based adjustments far earlier than is currently possible. Such an approach could significantly shorten the time to seizure freedom, improve treatment precision, and reduce the burden of prolonged uncontrolled seizures. While HV is generally considered a safe procedure, and is already currently used at home via telemedicine by some clinicians,[21] ensuring patient safety will be a bigger concern for at-home monitoring. Adequate education for caregivers on supervision of the procedure and adverse event responding will be critical. A study is currently in development to investigate the HV Recorder's efficacy and safety for monitoring in the home environment. Future research will also aim to refine HV protocols to maximize sensitivity—evaluating whether repetition of the procedure or adjustments in HV duration can further enhance the tool's value for both diagnostic screening and longitudinal treatment monitoring.

Conclusions

The Eysz HV Recorder provides a reliable, scalable, and accessible method for identifying absence seizures during HV. By taking a widely used clinical technique and rigorously validating it within a device-assisted platform, this study bridges traditional neurological practice with modern digital health innovation. This approach not only strengthens confidence in HV as a diagnostic tool for CAE but also provides a practical solution to reduce both over-referral of children with nonepileptic staring spells and under-recognition of absence seizures.

CRediT authorship contribution statement

Rachel Kuperman: Writing – review & editing, Writing – original draft, Resources, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization. **Nathaniel J. Blanco:** Writing – review & editing, Writing – original draft, Validation, Resources, Methodology, Formal analysis, Data curation. **Jeffrey Buchhalter:** Writing – review & editing, Data curation. **Sudha Kessler:** Data curation. **Kelly Knupp:** Data curation. **Nan Lin:** Writing – review & editing, Data curation. **Kelly Kremer:** Writing – review & editing, Data curation. **Gewalin Aungaroon:** Writing – review & editing, Resources, Project administration, Funding acquisition, Data curation.

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