Rejection of Non-seizures from Retrospective Video of Wristband Reported Epileptic Seizure Events

Jonathan Bidwell
Georgia Institute of Technology,
Atlanta, GA 30313, USA
bidwej@gatech.edu

Eliana Kovitch Thropp
Children's Healthcare of Atlanta
Atlanta, GA, USA
eliana.thropp@choa.org

Chiara Caborni
Empatica Inc.
Milan, Italy
cc@empatica.com

Francesco Onorati
Empatica Inc.
Milan, Italy
fo@empatica.com

Cherise Fraizer, M.D
School of Medicine,
Emory University
Atlanta, GA 30307, USA
cherise.frazier@emory.edu

Elizabeth E Mynatt
Georgia Institute of Technology,
Atlanta, GA 30313, USA
mynatt@gatech.edu

Abstract
This study investigates a new approach for improving the quality of patient and caregiver reported seizure counts when wearing seizure detection wristbands during epilepsy treatment. 5 patients with epilepsy (1 adult and 4 pediatrics) were instrumented with Empatica E4 seizure detection wristbands and were video recorded during inpatient Epilepsy Monitoring Unit (EMU) visits. The patients and patient caregivers reviewed videos of wristband reported seizure events. The wristband events were compared against a set of hand annotated video electroencephalogram (vEEG) observations made by certified EEG technicians as a ground truth. The participants successfully labeled 3 out of 3 seizure events and rejected 8 out of 8 false alarms. The results demonstrate that a video review can improve the performance of wristband reported seizure counts. In turn, the proposed video review approach stands to enhance clinical decision making by enabling patients and caregivers to overcome the issue of high false positive rates among the consumer seizure detection technologies prior to clinical appointments.

Author Keywords

Health tracking; Patient Self-reporting; Clinical Data Indicators; Neurocognitive

ACM Classification Keywords
J.3 LIFE AND MEDICAL SCIENCES, Health

Introduction

Epilepsy treatment can be especially challenging given the need for accurate patient and caregiver self-reports between appointments [1], [2]. Neurologists rely on patient and caregiver documented seizure events for evaluating and adjusting medications. In practice, patients and caregivers tend to underreport seizures [3]–[6] while consumer seizure detection technologies over report seizure events with many false alarms [7].

The purpose of this study is to investigate a new approach that utilizes commercial seizure detection wristbands and video recording for increasing the quality of patient and caregiver seizure reports during treatment. Instead of directly focusing on increasing seizure detection accuracy we instead investigated how we might enlist help from patients and caregivers for addressing both underreporting among patients and over reporting among devices.

The study included 5 patients who were diagnosed with epilepsy with 1 adult and 4 pediatric patients. The patients were each instrumented with seizure detection wristbands, and video recorded during 2 to 5 day, inpatient Epilepsy Monitoring Unit (EMU) visits. The wristbands detected the onset time and duration of probable seizure events. The recorded video later enabled patients and caregivers to review videos of the detected events with the aim of identifying and rejecting events that are false alarms (e.g. non-seizure related behaviors such as head scratching and typing a text message). The wristband-reported events were then compared against video-electroencephalography (vEEG) observations from certified technicians. The results showed that patients and caregivers can indeed increase the precision of wristband-reported seizure counts by correctly rejecting false alarms (8 out of 8 false alarms were rejected).

The main contribution of this work is a new approach for improving the quality of patient and caregiver seizure counts that are available to clinicians outside of hospital settings.

Related work

The proposed video review approach responds to the long-standing need to address a performance gap between current seizure detection devices [7], [8] and current patient and clinical self-reporting requirements during treatment [9].

The standard of care is to instruct families to maintain a "seizure diary" between regularly scheduled 1-6 month appointments. The diaries typically include the date, time and a description of seizure events. Having access to accurate seizure counts is particularly important for evaluating and adjusting seizure control medications [1], [2], however, families often fail to provide this information for the following three reasons:

1. Most patients and caregivers underreport seizures - Many patients struggle with seizure reporting, especially at night, due to impaired consciousness both during and following seizure events. In a study from Hoppe et al., [10] more than 85% of adult patients failed to report seizures that occurred while sleeping [10]; daily reminders to complete reports also did not improve self-reporting performance [10]. Similarly, patient caregivers often disagree on important seizure characteristics [11] and are often less able to observe patients at night [12].

2. Most devices over report seizures – In addition, most seizure detection devices over report patient seizures [7]. In our previous technology review, we showed that current seizure detection devices exhibited high false alarm rates with high recall and low precision [7]. For example, Narechania et al. [13] evaluated an MP5 pressure sensing mattress and reported a recall of 89.0% and a precision of 43.0% (i.e. more false alarms than missed seizure events).

3. Most devices are unsuitable for long-term use - Electroencephalography (EEG) devices are well suited for detecting seizures but require patients to wear uncomfortable electrodes and undergo specialized training to interpret EEG readings. By contrast, non-EEG seizure detection wrist and arm bands are considered more comfortable and practical for long-term monitoring yet report higher numbers of false alarms and thus fall short of patient and clinician requirements [7], [9]. It is, therefore, important to enable patients and caregivers to review seizures and address these performance requirements.

In response, we opted to directly leverage seizure detection wristbands and patient and caregiver input with the aim of developing a viable approach for increasing the accuracy of patient seizure counts that would otherwise be over reported at home.

Methods

The study was conducted at the Emory University Hospital and Children's Healthcare of Atlanta (CHOA) hospitals and included a total of 5 patients (1 adult and 4 pediatrics) during 2 to 5-day EMU visits.

Inclusion criteria for the participant sample included all adult and pediatric English-speaking patients with a diagnosis of epilepsy. Each patient had a prior history of seizures and were being observed as part standard epilepsy diagnosis or treatment. Informed consent was obtained from all participants. In addition, we gave caregivers the option of reviewing video on behalf of patients as deemed appropriate in the case of young patients and patients with developmental delays.

The video review process involved the following steps:

1. Measuring wristband-detected seizure events - The patients were each instrumented with a pair of Empatica E4 seizure detection wristbands on the left and right wrists [14] while being video recorded. The wristbands were used to record electrodermal activity (EDA) and accelerometer (ACM) measurements. The measurements were analyzed with the binary seizure detection classifier from Poh et al. [15] to detect the onset time and duration of probable seizure events. Then each wristband event was compared against the vEEG annotations to classify them as a "true positive", "false positive" or "false negative", respectively.

2. Indexing video of wristband-detected events - The recorded video was indexed by the wristband-detected seizure events. The video was clipped into short segments that spanned +/- 10-seconds before and after the onset of each wristband-detected seizure event. In addition, we randomly indexed up to two video clips per day for simulating false alarms.

The wristbands used a previously published seizure detection classifier that reported an average of two false alarms per 24 hours [15]. In practice, the wristbands often reported fewer than two seizures per day. Instead of disqualifying patients with low numbers of wristband reported seizure events, we simulated prior performance by randomly indexing up to two additional video clips. This guaranteed that each participant would review at least two clips per 24 hours of recording, and enabled us to further investigate the extent to which study participants could successfully reject false alarms.

3. Identifying and rejecting false alarms – The video review was conducted using a cross-platform screen sharing application called TeamViewer Live. The application enabled patients and caregivers to speak with the study coordinator and optionally control his mouse and keyboard during the video review.

The study coordinator scheduled a video chat meeting following the patient's EMU visit. The individual or joint groups of patient and caregiver participants then reviewed each video clip and reported either "Yes",

"Maybe" or "No" to indicate whether the patient appeared to be having a seizure in each video clip. EEG technicians annotated the onset and duration of seizure events using vEEG as a part of the patient's standard medical treatment. Then the participant's responses were compared against the EEG technician annotations to evaluate the extent that the participants correctly labeled wristband events as true and false positives.

Data collection

The study was conducted within EMU inpatient bedrooms and investigated the use of consumer hardware for collecting wristband and video data.

The study participants included a subset of patients from a larger data collection and evaluation study [17]. In practice, we had difficulty scheduling the video review sessions following each patient's EMU visit. This restricted our analysis to 5 patients with 1 adult and 4 pediatrics from Emory and CHOA, respectively.

The overall goal was to provide participants with a similar data collection and video review experience to performing long-term seizure reporting at home.

Seizure detection wristbands – The patients were instrumented with commercially available Empatica E4 wristbands on each wrist. The E4 wristbands had a battery life of 36 hours, a data storage capacity of 48 hours and recorded ACM and EDA measurements that were first uploaded to a web-server for analysis and then analyzed offline using the previously mentioned seizure detection classifier from Poh et al. [15].

EMU video recordings - The patients were video recorded 24/7 during the EMU visits. Each patient's bedroom featured a ceiling-mounted Sony IPELA EP520 (720 x 480-pixel resolution) for recording videos. An infrared illuminator facilitated video capture at night. The video quality was comparable to a consumer security camera such as the Foscam FI8918W [16].

Results

The participants correctly rejected 8 out of 8 false alarms. The video review required between 15-20 minutes for setup and 3 minutes for reviewing video clips on average. 2 out of 4 pediatric patients jointly reviewed video with a caregiver while the adult patient reviewed video clips independently.

Discussion

The results showed that introducing a video review can indeed increase the quality of automated seizure counts from a pair of wearable seizure detection wristbands. The patients correctly rejected all false alarms (5 out of 5 patients rejected 100% of false alarms).

The video review also satisfied important performance requirements. In a recent survey from Van de Vel et. al [9] clinicians reported that they would require seizure detection devices with "90% correct detections" with "between two false alarms per week and one per month" while patients required "one false alarm per seizure". If we assume that a patient has 2 seizures per week, then current seizure detection devices would fall short of these expectations with an average F1-score of 0.60 [7] as compared with the desired 0.90.

Informal interviews suggested that privacy would not be a chief concern among families. Interviews were conducted following each video review. Two caregivers remarked that they would like to see patient seizures at night, and when asked, the patients each said that they would be comfortable with having caregivers perform reviews on their behalf. In addition, three caregivers reported that conducting video reviews would provide them with considerable peace of mind as adolescent patients tend to sleep by themselves, and increasingly sleep away from home during camps and colleges.

In the future, the proposed video review process may be useful for collecting patient seizure counts in the home. The resources for building a video review system

are readily available. For example, security cameras such as the Foscam [16] support video indexing. These cameras could be used to index real-time seizure alerts from wearable devices such as the Embrace [18] and SmartWatch [19].

Next, the retrospective nature of the video review presents the benefit of enabling patients and caregivers to complete surveys at convenient times rather than on a strict daily or weekly schedule. Moreover, most adult patients are unaware of seizures while sleeping [10]. In turn, the promptness of reporting becomes less crucial as most patients will need to rely on video rather than memory for documenting seizure events.

Finally, patients and caregivers may require periodic reminders to ensure that they have sufficient time to complete review videos prior to appointments. For example, a patient that takes 3 minutes to review 1 week of video would need 72 minutes of review time prior to a 6-month appointment. It may, therefore, be beneficial for clinicians to be able to remotely monitor review status for sending email and SMS reminders to help distribute the workload over time.

Conclusion

The study examines the extent to which patient and caregiver video reviews can improve the quality of seizure counts that are reported using commercially available seizure detection wristbands.

The study investigated the use of Empatica E4 seizure detection wristbands and video recording equipment for enabling patients and caregivers to review and more accurately report patient seizure events during EMU visits. The wristbands reported seizure events that patients often miss while asleep or due to impaired consciousness during the day [10]. The video review enabled patients and caregivers to observe a video of the wristband detected events and reject false alarms that would otherwise contribute to inaccurate, over reported seizures during treatment. The participants successfully rejected all false alarms for increasing seizure reporting performance and were receptive to the idea of conducting video reviews in the home.

These findings provide a promising step towards first addressing the problem of over-reporting among mobile and wearable seizure detection systems by identifying 100% of false alarms and then further to address the problem of under-reporting among patients by enabling participants to record seizure events that they might have otherwise missed.

References

[1] R. S. Fisher, "Tracking epilepsy with an electronic diary," *Acta Pædiatrica*, vol. 99, no. 4, pp. 516–518, Apr. 2010.

[2] J. J. R. Jr, "Classification of seizures and epilepsy," *Curr. Neurol. Neurosci. Rep.*, vol. 3, no. 4, pp. 325–331, Jul. 2003.

[3] H. Blumenfeld, "Impaired consciousness in epilepsy," *Lancet Neurol.*, vol. 11, no. 9, pp. 814–826, Sep. 2012.

[4] D. E. Blum, J. Eskola, J. J. Bortz, and R. S. Fisher, "Patient awareness of seizures," *Neurology*, vol. 47, no. 1, pp. 260–264, Jul. 1996.

[5] F. Kerling, S. Mueller, E. Pauli, and H. Stefan, "When do patients forget their seizures? An electroclinical study," *Epilepsy Behav.*, vol. 9, no. 2, pp. 281–285, Sep. 2006.

[6] C. Hoppe, A. Poepel, and C. E. Elger, "Epilepsy: accuracy of patient seizure counts," *Arch. Neurol.*, vol. 64, no. 11, pp. 1595–1599, Nov. 2007.

[7] J. Bidwell, T. Khuwatsamrit, B. Askew, J. A. Ehrenberg, and S. Helmers, "Seizure reporting technologies for epilepsy treatment: A review of clinical information needs and supporting technologies," *Seizure*, vol. 32, pp. 109–117, Nov. 2015.

[8] A. Van de Vel *et al.*, "Non-EEG seizure-detection

systems and potential SUDEP prevention: state of the art," *Seizure*, vol. 22, no. 5, pp. 345–355, Jun. 2013.
[9] A. Van de Vel, K. Smets, K. Wouters, and B. Ceulemans, "Automated non-EEG based seizure detection: Do users have a say?," *Epilepsy Behav.*, vol. 62, pp. 121–128, Sep. 2016.
[10] C. Hoppe, A. Poepel, and C. E. Elger, "Epilepsy: accuracy of patient seizure counts," *Arch. Neurol.*, vol. 64, no. 11, pp. 1595–1599, Nov. 2007.
[11] F. J. Rugg-Gunn, N. A. Harrison, and J. S. Duncan, "Evaluation of the accuracy of seizure descriptions by the relatives of patients with epilepsy," *Epilepsy Res.*, vol. 43, no. 3, pp. 193–199, Mar. 2001.
[12] K. Detyniecki and H. Blumenfeld, "Consciousness of seizures and consciousness during seizures: are they related?," *Epilepsy Behav.*, vol. 30, pp. 6–9, Jan. 2014.
[13] A. P. Narechania, I. I. Garić, I. Sen-Gupta, M. P. Macken, E. E. Gerard, and S. U. Schuele, "Assessment of a quasi-piezoelectric mattress monitor as a detection system for generalized convulsions," *Epilepsy Behav.*, vol. 28, no. 2, pp. 172–176, Aug. 2013.
[14] "Real-time physiological signals - E4 EDA/GSR sensor," *Empatica*. [Online]. Available: https://www.empatica.com/e4-wristband. [Accessed: 02-Feb-2017].
[15] M.-Z. Poh *et al.*, "Convulsive seizure detection using a wrist-worn electrodermal activity and accelerometry biosensor," *Epilepsia*, vol. 53, no. 5, pp. e93–e97, May 2012.
[16] L. Shenzhen Foscam Intelligent Technology Co., "Foscam FI8918W User Manual."
[17] Francesco Onorati, PhD, Giulia Regalia, PhD, Chiara Caborni, Matteo Migliorini, PhD, Daniel Bender, Ming-Zher Poh, PhD, Cherise Frazier, MD, Eliana Kovitch Thropp, CPNP, Elizabeth D. Mynatt, PhD, Exec Dir, Jonathan Bidwell, Roberto Mai, MD, William Curt LaFrance, Jr, MD, MPH, Andrew S. Blum, MD, PhD, Daniel Friedman, MD, Tobias Loddenkemper, MD, Fatemeh M Touserkani, MD, Claus Reinsberger, MD, PhD, Simone Tognetti, PhD, and Rosalind W. Picard, "Multi-center clinical assessment of improved wearable multimodal convulsive seizure detectors," *Epilepsia*, 2017 (submitted).
[18] "Monitor stress, seizures, activity, sleep," *Empatica*. [Online]. Available: https://www.empatica.com/product-embrace. [Accessed: 03-Mar-2017].
[19] A. L. Patterson *et al.*, "SmartWatch by SmartMonitor: Assessment of Seizure Detection Efficacy for Various Seizure Types in Children, a Large Prospective Single-Center Study," *Pediatr. Neurol.*, vol. 53, no. 4, pp. 309–311, Oct. 2015.