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Detection is Key: Automated Tonic Seizure Detection With a Wearable Device

Automated detection of tonic seizures using wearable movement sensor and artificial neural network

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Although several validated wearable devices are available for the detection of generalized tonic-clonic seizures, automated detection of tonic seizures is still a challenge. In this phase 1 study, we report the development and validation of an artificial neural network (ANN) model for automated detection of tonic seizures with visible clinical manifestation using a wearable wristband movement sensor (accelerometer and gyroscope). The dataset prospectively recorded for this study included 70 tonic seizures from 15 patients (7 males, age 3-46 years, median = 19 years). We trained an ANN model to detect tonic seizures. The independent test dataset comprised nocturnal recordings, including 10 tonic seizures from 3 patients and additional (distractor) data from 3 subjects without seizures. The ANN model detected nocturnal tonic seizures with visible clinical manifestation with a sensitivity of 100% (95% confidence interval = 69%-100%) and with an average false alarm rate of 0.16/night. The mean detection latency was 14.1 s (median = 10 s), with a maximum of 47 s. These data suggest that nocturnal tonic seizures can be reliably detected with movement sensors using ANN. Large-scale, multicenter prospective (phase 3) trials are needed to provide compelling evidence for the clinical utility of this device and detection algorithm.

Commentary

Real-time seizure monitoring devices are appealing for many reasons. For clinical trial investigators, to track accurate seizure counts during a study period rather than rely on seizure diaries[1,2]; for providers, to know how frequently their patient is truly having clinical seizures and if the current therapies are efficacious; for patients who live alone, to get a sense of how frequently they are having unwitnessed seizures; and for caregivers, to get alerts when their loved one is having seizures.[3,4] Several monitoring devices have been investigated and assessed for validity. These have been most successful for seizures with prominent motor features, specifically generalized tonic-clonic seizures or focal to bilateral tonic-clonic seizures.[5,6] One issue with commercially available devices and previously investigated devices is a high false-positive rate which can limit real-world applicability and lead to discontinuation of use by patients and caregivers.[7]

Larsen et al. present the results of their phase 1 study on the development and validation of an automated neural network (ANN) model trained to detect tonic seizures using a wearable wrist sensor.[8] Their wristband sensor included an accelerometer and gyroscope, which collected 6 continuous axis measurements, with a threshold for feature extraction of a minimum acceleration of 0.1 g. Features were extracted in 10-s intervals with 1-s overlap, with 594 features, such as mean, variance, and standard deviation, extracted for each of the six sensor readings. Enrolled patients were monitored using the author's epilepsy center's standard of care in the epilepsy monitoring unit, including video-electroencephalography (vEEG) and surface electromyography (sEMG) electrodes. Video-EEG recordings were independently reviewed by 2 experts, blinded to the sensor data, who assessed for tonic seizures during the recording periods of 1 to 3 days for the subjects. Fifteen patients aged 3 to 46 years, with tonic seizures detectable on both vEEG and sEMG, were included. Data on tonic seizures was split for training of the algorithm and for testing. Additional subjects with tonic seizures were recruited for the test dataset which was compared to nocturnal data for subjects without any history of seizures for evaluation of specificity and the false alarm rate. The automated neural network was developed and validated using the independent test data.

Results were notable for accurate detection of tonic seizures and a sensitivity of 100% using the independent dataset. The false alarm rate was 0.023/h in the same dataset. For the complete dataset, the sensitivity was 96% with a false alarm rate of 0.23 per night. Looking at the entire dataset, which included 18 patients, the median false alarm rate per patient was 0 per night, with expected triggers for false alarms for tonic seizures including voluntary movements, arousals from sleep, and physiologic movements during sleep. Overall, these results show significant promise in the future development of wearable

technology which can accurately detect nocturnal tonic seizures with a low false positive rate.

While the results of Larsen and colleagues show that improvements in seizure detection devices are on the horizon, the authors acknowledge several limitations. This study population, particularly the independent test pool, was small and therefore, future phase 3 studies, with real-time seizure detection, are needed for further validation of this model and determination of the clinical applicability of this ANN. Another point was that this algorithm and the data collected were complex, with the ANN and analysis done offline (i.e., not in real-time) on a PC and not through embedded software in the wristband device. If additional complexity or further parameters are needed, would this be something that can be translated to the wearable device and still retain the same degree of accuracy? This also brings up one of the authors' other points—patients with nocturnal tonic seizures typically have other seizure types and many times a Lennox-Gastaut syndrome phenotype. Other algorithms, such as one targeting generalized tonic-clonic or focal to bilateral tonic-clonic seizures,[9] would need to be run in parallel and would likely result in a higher false positive rate. The study also excluded subtle tonic seizures which did not have a clear motor component but was picked up by sEMG, which did not account for many seizures in this cohort.

Currently, there continue to be challenges in translating artificial intelligence into epilepsy clinical practice. We can look individually at a wearable device, or detection of a single seizure type, or a set of machine learning models, but this is still just a fraction of the information needed compared to the large amount of rigorously reviewed, high-quality, standardized data necessary for true clinical translation into practice.[10] As with other epilepsy research, multicenter collaboration is important for sharing data and algorithms to assist with the collection of standardized data in the development stage and to test generalizability later. In the current example of seizure detection, the likelihood of accurately detecting seizures would be low and the false positive rate high if the data quality and breadth were insufficient, and generalizability were not adequately tested.

Larsen et al.'s study was performed in their epilepsy monitoring unit under ideal settings. In a real-world environment, would the studied detection algorithms perform as well? Many potential confounders need to be considered, including environmental factors, such as signal interference from the abundant number of electronics that the patient will encounter on a day-to-day basis; patient factors, like excess movements due to physical activity effecting sEMG inputs; and device factors, such as battery life and durability. Other real-world considerations include the needs and resources of patients and caregivers. Seizure monitoring devices can be cost-prohibitive for some patients, as devices may or may not be covered by insurance and there typically exist monthly subscriptions for service. Wearable device users tend to skew toward higher-income patients and caregivers.[3] The requirements of a stable internet connection for data uploading or Wi-Fi of Bluetooth, for communication of the sensor with the control unit, may not be available in rural areas, or those from lower income or underserved populations. The comfort level of the wearable over time, annoyances with battery life or poor Wi-Fi signal, or other connectivity issues also play a role in how successful a device can be.[11]

Real-time seizure detection devices can be appealing to patients and caregivers, by reducing anxiety about unwitnessed seizures, providing a sense of safety, and potentially providing a greater sense of independence for some.[3,4] For clinicians, having an accurate seizure count can be extremely helpful to assess whether a current treatment regimen is successful or not; for research, accurate seizure diaries can make or break a study; however, for patients who live alone, do not recall their seizures, have unreliable witnesses, or who do not accurately record seizures, this can be a challenge.[1,2]

While far from ready for commercial use, the present study certainly brings hope that there continues to be progress in the landscape of seizure detection devices. This is certainly something that frequently is asked about in my clinic by families and caregivers. From both the clinical and research perspectives, I think that having accurate seizure counts and classification of seizures would be a great boon. From a parent or patient perspective, I can also see how having an accurate wearable device that has a low false alarm rate would reduce anxiety and potentially improve health-related quality of life.

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