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Detection of generalized tonic-clonic seizures from ear-EEG based on EMG analysis

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ABSTRACT

Purpose: Sudden unexpected death in epilepsy (SUDEP) is associated with generalized tonic-clonic seizures (GTCS) with most deaths occurring during sleep. Seizure detection devices have been suggested as a SUDEP prevention strategy. EMG-based GTCS detection can take advantage of the GTCS characteristic of sustained high-amplitude, high-frequency activity in the time-domain.
Method: We present a GTCS-detection method based on median-filtered variance estimates on surface EMG measurements and describe its performance in a small exploratory proof-of-concept setting involving a group of 15 patients with 3 GTCS recorded with ear-EEG and another group of 6 patients with 11 GTCS recorded with scalp-EEG.
Results: GTCS intervals were detected within 4.2-12.9 s of onset with 100% sensitivity (CI 29.2–100%) without false positives in 820.7 h of ear-EEG. The same detection method worked for the 11 GTCS from scalp EEG data with 100% sensitivity (CI 71.5–100%) and no false positives.
Conclusions: Ear-EEG contains enough GTCS-specific EMG activity for GTCS detection to be feasible. Ear-EEG could be considered for nocturnal GTCS monitoring as a supplement to SUDEP preventive interventions.

1. Introduction

The incidence of sudden unexpected death in epilepsy (SUDEP) varies by type of epilepsy from 0.9–2.3 per 1000 person-years in the general epilepsy population to 1.1-5.9 per 1000 person-years in patients with chronic refractory epilepsy. Generalized tonic-clonic seizures (GTCS) is the most important risk factor with higher seizure frequency linked to greater risk of SUDEP [1]. Compared to no yearly GTCS, a seizure frequency of 1–2/year is associated with an odds-ratio (OR) of SUDEP of 5.1, increasing to 15.5 at three or more yearly GTCS [2]. Nocturnal GTCS is an independent risk factor for SUDEP (OR 2.6) and SUDEP occurs more often during the night and is mostly unwitnessed [3] and a majority are found lying dead in the prone position [4]. There is evidence that nocturnal supervision has a protective effect concerning SUDEP risk [5] and it has been suggested that medical devices for seizure detection can support SUDEP prevention [2].

Seizure detection for GTCS using accelerometry is aimed at identifying the clonic phase and various studies have reported performance with sensitivities between 11 and 100% and false alarm rates ranging between 0.2 to 4/day [6]. Compared to accelerometry, surface EMG (sEMG) can detect the tonic phase of GTCS better and thus work with shorter detection latencies; median detection latency 17.0 s compared to 13.7s, respectively [7,8]. The sEMG detection strategy can rely on different features: Changes in median frequency, root mean square and EMG-EMG coherence can separate 63 GTCS from 20 patients from 100 simulated seizures acted by volunteers [9]. Later, an algorithm based on the number of zero-crossings achieved 100% sensitivity and 1 false positive/24 h when tested on 22 GTCS from 11 patients [8]. Beniczky et al. used a multivariate analysis of time-domain and frequency domain features to demonstrate detection of GTCS and differentiation from psychogenic convulsive seizures in recordings from a mobile device worn on the upper arm [10].

Ear-EEG a wearable EEG recording method, where electrodes are placed in and around the ear. Ear-EEG is of particular interest for long-term monitoring in epilepsy [11,12] and sleep [13,14]. Ear-EEG has also been used for hearing threshold estimation [15]. Physiological EMG-artifacts, particularly those elicited from jaw

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movements, are visible in ear-EEG measurements [16]. Thus, it seems plausible that the generalized muscle-activation pattern characteristic of GTCS could be detected using ear-EEG.

The objective of this study was to investigate the feasibility of using ear-EEG for GTCS detection.

2. Methods

2.1. Measurements

EEG was obtained from 15 patients admitted to the epilepsy monitoring unit (EMU) at Zealand's University Hospital and participating in a study of ear-EEG for suspected temporal lobe seizures. Simultaneous 25 channel scalp EEG and 8-channel binaural ear-EEG of durations between 1 and 4 days were collected. Patients were admitted on a primary suspicion of temporal lobe epilepsy, but among the seizure episodes some were of GTCS type and we refer to those in the following. For this study, we are only interested in the surface EMG component of the measurements. Intervals, where recording conditions were unsatisfactory because of high impedances or dislodged ear-EEG devices, were visually identified and removed. Sampling frequency for both scalp and ear-EEG was 256 Hz for five patients and 1024 Hz for the other ten patients including all those with GTCSs. For the same analysis to be performed on all data sets, we resampled the five datasets sampled at 256 Hz to 1024 Hz. Fig. 1 (panel 1 and 2) shows the ear-EEG device, how it is placed into the ear and the electrode locations. The electrodes were labelled E, I, B and A with the prefix L/R denoting left or right. References were bipolar and defined as either "intra-ear", when created from the six possible combinations of ipsilateral ear-electrodes, or "inter-ear", when the reference was the same-labelled electrode in the contralateral earpiece. Full description of the measurement and study population is described in our previous study [12]. Data were exported as edf-files and imported into Matlab R2017a for further analyses. The study was done in accordance with the Helsinki Declaration and was approved by the regional ethics committee (110724815).

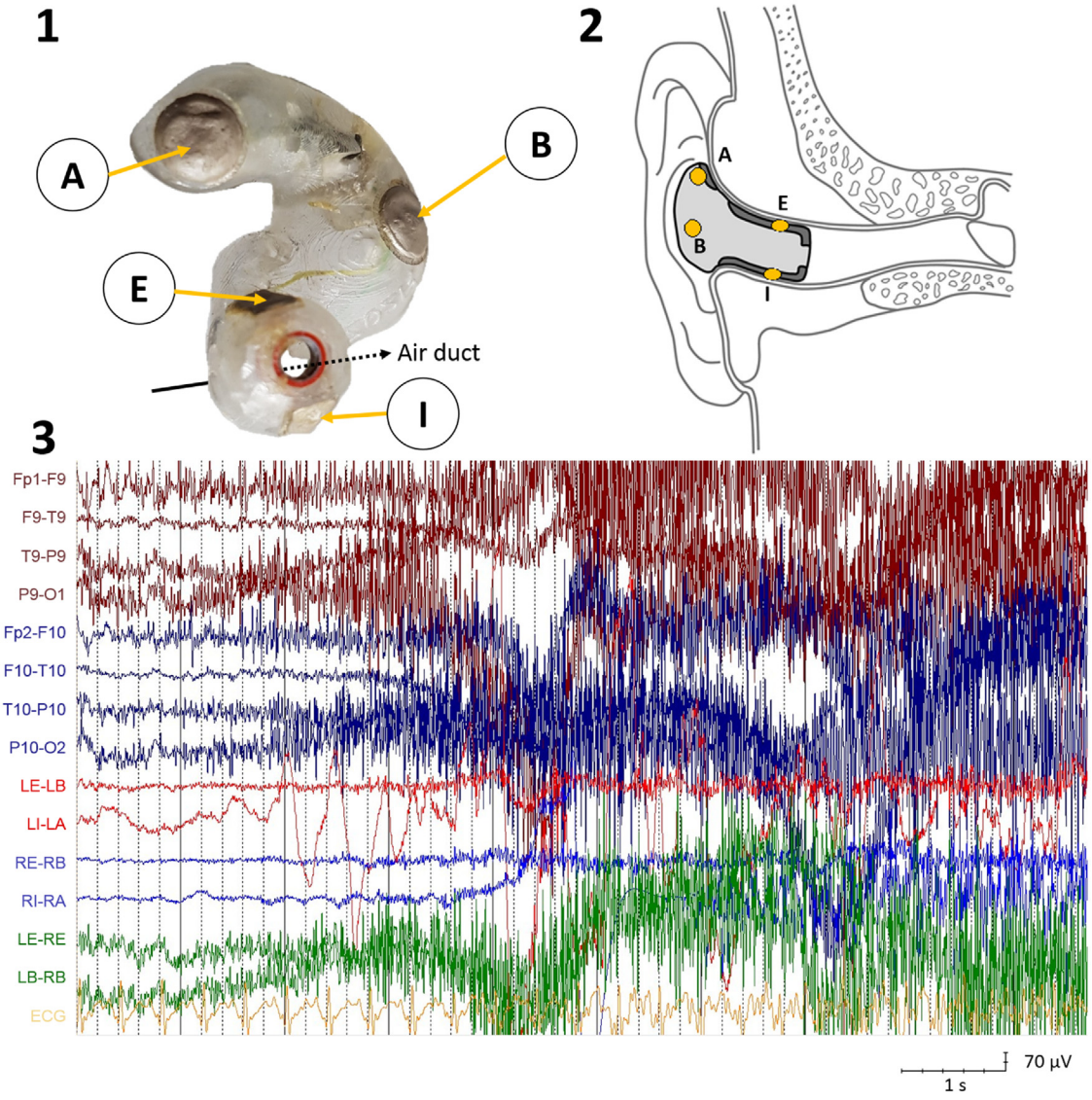

Fig. 1. 1) Photograph of the ear-EEG prototype we used. Right ear-piece. Labels A, B, E and I denote the electrodes and arrows point to their location on the earpiece. Note that there is an air duct for normal sound conductance. 2) Sketch of how the device is placed in the ear and the electrode locations. 3) Seizure onset for one of the GTCS we recorded, 8 longitudinal scalp channels displayed first. Below are two left intra-ear channels (LE-LB and LI-LA) displayed in bright red. Homologue right sided ear channels in bright blue. Inter-ear channels LE-RE and LB-RB are shown in green. Notice the lower amplitudes for the intra-ear channels. The distinct seizure pattern can better be appreciated in the inter-ear channels.