

Exploring Epileptic Seizure Detection with Commercial Smartwatches

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Abstract—Some forms of epilepsy can randomly trigger severe seizures that degrade patients’ quality of life and may even lead to death. Specially trained dogs that go through a long learning process can sometimes help to warn patients of an imminent seizure, possibly due to an ability to sense subtle changes in the subject’s blood oxygen level.

In this paper, we present our exploratory study of using a commercial smartwatch with an oxygen sensor to continuously capture data and detect changes in blood oxygen saturation during or ahead of a seizure to warn the patient or emergency contacts. Our data shows a possible correlation between reported oxygen level and a seizure incident, but higher-frequency readings will be required in the future to determine whether accurate prediction with smartwatches is indeed possible.

Index Terms—smartwatch, epilepsy, seizure, prevention, blood oxygen, sensor

I. INTRODUCTION

A chronic disease like epilepsy can have a severe influence on the quality of life of the affected person. During epileptic seizures, the patient may experience loss of perception of their surroundings, short term memory loss, and in severe cases even loss of the body’s sensorimotor functions (e.g. falling and convulsions). In some patients, these seizures occur unpredictably, therefore they cannot drive vehicles and are limited in choosing their occupation and physical activities. The prediction of an imminent seizure helps in reducing harm and improves life quality in general. In some cases, specially selected and trained dogs can predict and warn, but these dogs are hard to find, take years to train, and are very expensive. It is assumed that these dogs’ successful seizure predictions are based on their ability to detect drops in blood oxygenation [14], although the exact mechanism is not yet understood. Modern smartwatches continuously monitor physiological data such as heart rate and blood oxygenation, providing a constant stream of information suitable for ad-hoc evaluation and emergency reporting. In this paper, we explore whether a commercial smartwatch can provide some of the benefits of epilepsy dogs. In particular, we explore and compare sensor data recorded over several days from an epileptic patient and a control subject using a Garmin smartwatch, and correlate this data with manually logged seizure incidents provided by the patient.

While the data from our deployment indicates that smartwatches’ sensor readings might be useful for seizure detection,

the dataset is too small for statistical analysis. More data needs to be gathered to definitely answer the question of whether seizure detection or even prediction at a reliable accuracy level is possible. Nevertheless, our results show that commercially available smartwatches could be useful for further research concerning epileptic seizures and might aid in seizure detection and prediction.

II. BACKGROUND

We now introduce some core concepts related to this paper. First, we provide an introduction to epilepsy, followed by a discussion of relevant bio-signals. Finally, we review related work regarding the connection between epilepsy, smart devices and seizure detection/seizure prediction.

A. Epilepsy

Worldwide 0.5-1% of people suffer from epilepsy [10]. An epileptic can have seizures which vary in their degree of severity and the types of symptoms. During a seizure, there is an excessive amount of neuronal activity in the brain, often referred to as an ‘overcharge of the brain’.

An epileptic seizure can be triggered by various factors including flashing lights/patterns (photosensitive seizure), stress, lack of sleep, alcohol, or sudden scares. For roughly 70% of epileptics, seizures can be reduced or eliminated by correct medication or surgery, though there remain patients who never get rid of their seizures [18].

Seizures can be differentiated into *Focal Aware Seizures (FAS/auras)*, *Focal Impaired Awareness Seizures (FIAS)* and *bilateral tonic-clonic seizures* [17]. During a Focal Aware Seizure (also called *aura*), the epileptic is conscious and can later describe the symptoms. An aura lasts only for a few seconds and affects the sensitive and/or vegetative system. These symptoms are only perceived by the epileptic and not the people around them. Such sensations are described as an intense feeling of joy or fear, déjà vus, weird smells, or numb limbs. In contrast to other seizure types, the epileptic can remember having had an aura and how it felt, though during the aura itself the patient cannot always express that they are experiencing an aura.

On contrary, during a FIAS, the affected person has reduced consciousness during the seizure and often does not remem-

ber the seizure and what happened right before. Symptoms include, among other things, redoing the same movements, repeating the same phrase or question over and over or walking around without a destination [16].

A bilateral tonic-clonic seizure occurs when the FIAS spreads to both hemispheres of the brain, usually lasting from a couple of seconds up to 2-3 minutes. It might lead to blinking and staring into nothing, falling over, and/or losing consciousness. Other effects on the body include sweating, disruption of the digestive system, and convulsions (muscle spasms) [28].

If a seizure lasts longer than 5 minutes it is called *Status Epilepticus*. This ongoing seizure can quickly become life-threatening, as the heart rate becomes either too fast or too slow and the oxygenation of the body is no longer guaranteed [9]. In severe cases, even breathing is reduced or stopped during a seizure. If an epileptic dies, either due to a Status Epilepticus or due to other effects from the seizure, it is called *Sudden Unexpected Death in Epilepsy (SUDEP)*. 7-17 % of epileptics die suddenly without a comprehensible cause [6]. A device monitoring for seizures and life-threatening symptoms could reduce the number of SUDEPs and also help caregivers and family members.

B. Physiological Data

We focus on the physiological data values which could be measured through our wrist-worn device.

1) *Heart Rate*: The heart rate is usually defined as beats per minute (bpm). The resting heart rate, i.e. the ordinary heart rate throughout the day for an adult, is somewhere between 60-100 bpm. Physical exercise, anxiety, alcohol consumption etc. can increase the heart rate. During sleep, a heart rate of 40-50 bpm is common, though if it drops below 50 bpm while awake, this may indicate health issues and can lead to dizziness or fatigue. The heart rate can be measured on the wrist using an optical pulse sensor.

2) *Heart Rate Variability*: The heart rate variability (HRV) describes the statistical variation of the time interval between two heartbeats. E.g. the heart might beat 60 times per minute, but the duration between each heartbeat (RR value) is not exactly one second. In fact, it is healthy if there is a high variation in RR values, meaning that the body is capable of adaption to changing environmental conditions. HRV can be directly calculated from heart rate data.

3) *Oxygen Saturation*: Oxygen saturation (also called blood oxygen level) is a metric that defines the amount of oxygen circulating in the blood. The blood oxygen level is measured in per cent and lies between 95-100% for a healthy person. Below 80%, mental functions can be impaired and below 75%, loss of consciousness can occur [21]. This value is referred to as SpO₂ (saturation of peripheral oxygen) and can be measured on the finger or wrist by shining red and infrared light through the skin and detecting ratio of absorption/reflection.

III. RELATED WORK

A. Seizure Detection with Smart Devices

A leading company in the field of seizure detection is *empatica* [15], who has built their own FDA-approved wristband for real-time monitoring. Their main goal is to reduce the number of SUDEP cases by informing emergency contacts in case of a seizure. In one study, Onorati et. al monitored a patient for more than a year and sent alarms when their device detected a seizure. The false alarm rate was lower than 0.4% and the sensitivity over 97% [26]. In another study by *empatica's* researches [8], it was explored how to detect non-convulsive seizures using heart rate, blood oxygen and electrodermal activity. They found a change in both heart rate and EDA and claim that these sensors might be useful in detecting non-convulsive seizures. The paper does not mention blood oxygen in the results, so it is unclear if and how this data has changed during the seizure. Cogan et al. [12] also analyzed several biosignals, including heart rate and blood oxygen level, in a clinical setting and concluded that these signals are sufficient for accurate seizure detection.

Another study [27], focusing on generalized tonic seizures, asked 40 subjects with a risk of generalized seizures to wear the *empatica* wrist band. They used the data from the accelerometer and EDA to detect seizures. A sensitivity of more than 94% was found and the false alarm rate was lower than 0.25/day, based on accelerometer data to detected a fall. *Seizalarm* [5] helps people who often have auras to inform others about the possibility of an oncoming tonic-clonic seizure. Additionally using heart rate and the accelerometer of either an Apple Watch or an iPhone, automatic seizure detection is performed and emergency contacts are informed about the seizure. No data about the accuracy of seizure detection is currently available.

Neurava [25] built a device which is worn around the neck and collects biological signals, to detect and track seizures and alert caregivers. No detailed data about their product is currently available either.

Another product which is mentioned by several epilepsy organizations [2] is *BioStamp* by mc10 [1]. This small, unintrusive device can be placed at various positions on the body to collect several kinds of data. More research on seizure detection using *BioStamp* is expected in the future.

The market for seizure detecting devices and apps is slowly growing as sensors become smaller and more easily available. It underlines the importance of understanding how much commercially available devices can do to improve and contribute to the research. It also shows that seizure detection is possible using smart devices, which, if done correctly, can even save lives.

B. Seizure Prediction

In contrast to seizure detection, seizure prediction does not look for the symptoms that happen during a seizure but aims to find out what happens before a seizure. Detecting this so-called

preictal state could make it possible to warn the epileptic of an oncoming seizure.

1) *Sensor-based prediction*: Freestone et. al [20] conclude in their work that clinical seizure prediction could be possible if enough biomarkers are collected and model-based analysis is applied, though they did not conduct any research of their own. Some research on seizure prediction using sensors is done by analyzing long-term EEG data [11], concluding that algorithms could detect the preictal state before a seizure but only under certain circumstances. A study by Kiral-Kornek et. al [19] used intracranial electroencephalography (IEEG). The data from 10 patients were analyzed using deep learning mechanisms, with a resulting mean sensitivity of 69% (positive seizure prediction rate).

2) *Seizure Dogs*: Seizure-response dogs are presumably able to predict a seizure up to 4 minutes before so that the affected person has time to get in a safe position, ask others for help or take medicine. In a study by Dalziel et al. [13] 185 people with epilepsy filled a questionnaire. 29 subjects reported having a dog. Of these, nine claimed that their dog reacted to seizures, though only three said the dog reacted a couple of minutes before a seizure. Even though this small set doesn't allow for statistical analysis, the authors conclude that demographic attributes of the subjects do not seem to affect the dogs' ability to predict a seizure and neither does the race and age of the dog. Though the study ended up with only a small subject group, it was the first to ever explore the idea that dogs can predict epileptic seizures.

The Alberta Children's Hospital (ACH) in Canada found in their study in 2004 [24] that the dogs who could predict seizures did so in 80% of all occurring seizures with no false positives [22]. 15% of the dogs in the study had this ability, mostly large dog breeds. The authors concluded that the ability to predict seizures was something the dog was born with, instead of trained. This hypothesis has not yet been disproven, even though training is necessary to receive the desired reaction from the dog during a seizure. Another study by the ACH in 2007 showed that having a seizure-alerting dog also seemed to decrease the duration, intensity and even frequency of the seizures [14].

In 2013 the Deutsche Assistenzhunde Zentrum (DAZ), the German Center for Service Dogs, conducted an experiment to find out what triggers a seizure dogs warning behaviour [14]. 24 subjects and 14 dogs participated in the study. The subjects consisted of patients with diabetes, focal epilepsy, migraines, asthma, and 12 subjects without known health conditions as a control group. All of the 14 dogs were known to have the ability to warn. During the experiment, a subject was always paired with one of the dogs and had their blood oxygen level measured continuously. Both stayed in a room while being monitored. For the control group, the blood oxygen levels were mostly steady and the dogs did not show any warning behavior. The other subjects showed some changes in their level of blood oxygen. Subjects with diabetes showed a slight decrease (3%) shortly before they experienced a hypo- or hyperglycemia. Subjects with asthma and migraine also showed a decrease

in blood oxygen before an attack. For subjects with epilepsy, the blood oxygen value decreased before and during the attack. For all groups, the dogs warned the subjects as soon as the blood oxygen changed by more than 3%. The dogs started to lick the subjects' hand, nudge them, or put a paw on their lap. This study seems to indicate that the dogs indeed can perceive the change in blood oxygen and react to this change, as the dog warned for the whole duration the blood oxygen was low.

IV. STUDY

As is shown in section III, specialized smart devices and service dogs can improve the life quality of an epileptic. Therefore, our core research question is: *can commercially available smartwatches be used for seizure detection and/or prediction?* In our study, an epilepsy patient and a control subject were monitored using a smartwatch for several days and the collected data was used for qualitative analysis.

1) *Smart Device*: The smart device used for monitoring had to fulfil several requirements: 1) heart rate sensor, 2) blood oxygen sensor at the wrist (SpO₂), 3) real-time monitoring capability, 4) available SDK for watch apps. Even though most smartwatches have a sensor for measuring the heart rate, few have one for blood oxygen. At the time the watch was chosen (December 2019), only some watches by Garmin [4] had the sensor integrated and active. Withings [7] and Fitbit [3] include sensors in their watches, but they were not activated at that time. Some off-brand devices also offered SpO₂ sensors, but they lacked detailed information about their sensors and sensitivity, thus were disregarded. Based on these criteria, we selected the Garmin Vivosmart 4. Garmin offers an SDK which allows receiving the data in real-time, which we used for our data collection app with an evaluation license.

2) *Subjects*: Two subjects were chosen for data collection. Both consented to the anonymized use of their data. First, a 31-year-old male, who will be referred to as the patient. He became an epileptic after suffering from encephalitis at age 24 and was diagnosed with focal epilepsy after suffering several seizures. The patient sometimes goes without a seizure for up to 2 weeks, but at other times he has several per week or even per day. He knows several triggers which can cause a seizure, such as emotional stress, being startled, alcohol consumption, or an unstable sleep schedule. However, not all his seizures account for one of these triggers and can occur without any perceivable cause. His seizures range from having an aura to tonic-clonic seizures with convulsions. The control subject is a 30 years old male and has never had a seizure, nor does anyone in his family have epilepsy. We note that the patient occasionally smokes cigarettes, while the control subject does not; however, as Jeon et al. [23] show, cigarettes do not have short-term effects on the SpO₂ value (despite numerous other detrimental effects).

3) *Data Collection*: Both subjects were monitored using the Garmin Vivosmart 4. During the experiment, the daily routine for both subjects didn't include any physical activity and was mostly spent at home with calm activities like studying, reading and watching TV. The subjects were asked to

wear the watch and keep a smartphone close by, which served as a data receiver. The data (heart rate and blood oxygen) was sent to a server in real-time. The API also provides *stress level*, an aggregate measurement calculated from the raw data by a proprietary Garmin algorithm. We collected this value for a subset of the total time period, but as no information about the calculation is available, we cannot currently draw any conclusions from this data. The control subject was monitored for 3 days in a row (March 2020). The patient was monitored for a longer time period as we waited for seizures to occur during the monitoring (April - May 2020). In total, he was monitored for 12 days resulting in nine days with useful data (see also discussion). Additionally, he and his spouse were asked to note the time and severity of any seizure occurring during this period.

TABLE I: Seizures and auras reported by the patient and/or his spouse. The exact time for all seizures is not known, as there were times where the subject was alone and was found afterwards with clear indications of having had a seizure.

Date	Time	Type
30.04.20	19:58	convulsive
01.05.20	09:19	convulsive
01.05.20	afternoon (14-17)	unknown
17.04.20	evening (20-23)	unknown
18.04.20	19:56	Aura

V. RESULTS

First, we compare the data from both subjects. Next, data from the patient is mapped to seizure incidents to analyze if a seizure is perceptible in the data.

1) *Collected Data*: There were two collection periods, from April 30th to May 5th and from May 17th to 21st. For the control subject, heart rate and blood oxygen were gathered on three consecutive days. Table I shows the date and time of seizures reported during the data collection period.

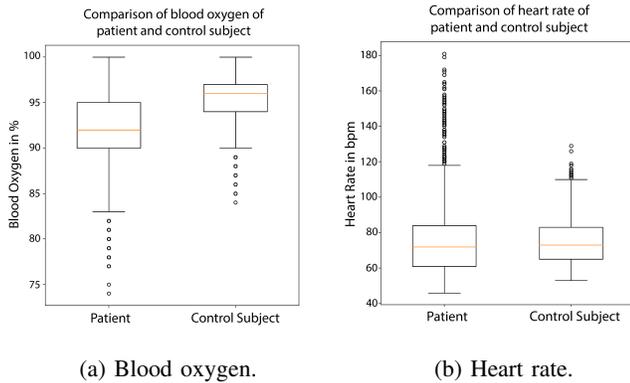


Fig. 1: Aggregated data for patient and control subject.

The data was preprocessed and cleaned before analysis, removing exact duplicates and null values. A bug in the data collection app led to some parts of the data being lost. This defect is visible in the graphs throughout this section and

should be kept in mind when looking at the visualizations. A similar problem is the low frequency of the blood oxygen readings. The watch usually collects blood oxygen data only when it detects little to no movement (i.e. mostly during the night), therefore noticeably fewer data points were gathered throughout the day.

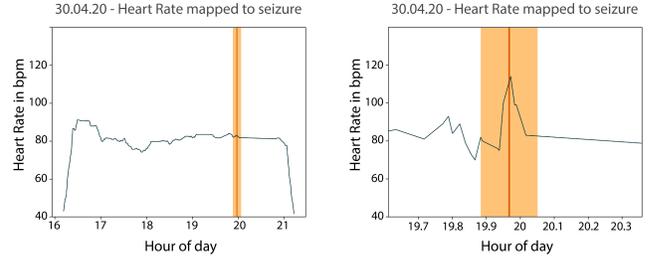


Fig. 2: Heart rate for patient mapped with a seizure on the 30.04.2020. The seizure occurred at 19:57, which is indicated by the vertical red line. The orange bar indicates an uncertainty interval. On the left is a smoothed overview of the heart rate while the right figure provides a more detailed look at the data. During the time of the seizure the heart rate increased from 75 bpm to 113 bpm.

2) *Comparison with control subject*: In total, for both subjects roughly 38500 datapoints each for blood oxygen were collected. We analyze how many of the blood oxygen values were below 90%, because this is a conservative lower boundary for healthy persons. Almost 25% of all collected blood oxygen values for the patient were below this limit, while for the control subject it was only about 0.7%. During the day, less data was collected due to the internal settings of the smartwatch. Nevertheless, the patient's blood oxygen was low more often compared to the control subject (9% in comparison to 0.6%).

Figure 1a visualizes the blood oxygen values for both subjects. The mean for the whole monitoring period was 92% for the epileptic patient and 96% for the control subject. The patient has the lowest SpO2 value at 74% compared to 84% for the control subject.

Figure 1b shows an aggregated visualization of the heart rate data. The heart rate for the patient shows to have a larger range compared to the study subject and sometimes reaches critical values (> 140 bpm). The heart rate will not be used for between-subject-comparison here, as it can vary strongly between people and would need to be mapped to the activity of the subjects.

3) *Mapping Data to Seizures*: To see if a seizure could be detected or predicted, the reported seizures were mapped to the data using line charts. We first take a look at each of the data types (heart rate, blood oxygen and stress) and then at a combination of all of them. A seizure is indicated by a vertical red line in the line chart and the orange bar to its sides indicates a time interval of 5 minutes before and after the seizure was reported.

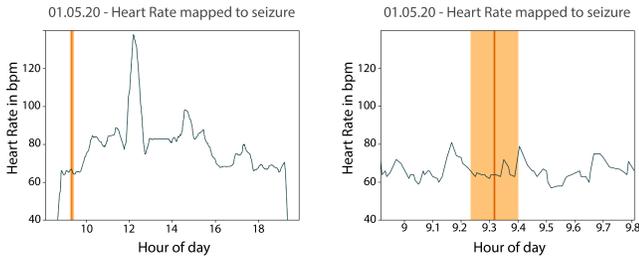


Fig. 3: Heart rate for patient mapped with a seizure at 09:19 on the 01.05.2020. The left figure shows a smoothed overview of all data collected on that day and the right a detailed view. The heart rate during the seizure was at 62 and increased to 72 shortly after.

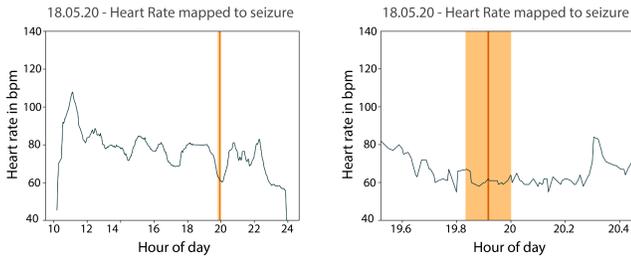


Fig. 4: An aura occurred at 19:56 on the 18.05.20. The left side is a smoothed representation of all data collected at that day and the right side a detailed view. The heart rate before, during and after the seizure was in a range of 57 and 64 without any obvious spikes.

4) *Heart Rate*: Figure 2 shows the heart rate on the 30.04.2020 and a seizure reported at 19:57. The graph shows a spike in heart rate of roughly 40 bpm shortly after the convulsive seizure and then falls again by 30 bpm. During the seizure on the 01.05.20 (figure 3) and the aura in figure 4 the heart rate is at roughly at 62 bpm and no such spikes can be seen. In figure 4 there is a steady drop in the heart rate starting 30 minutes before the seizure.

5) *Blood Oxygen Values*: Next, the patients' blood oxygen data is mapped to the seizures. Figure 5 shows a clear drop of almost 20% right around the time the seizure was reported and a slow rise in the next 5 minutes. This seizure contains also the absolute minimum of the SpO₂ data for all of the collected data (74%). It was reported as a convulsive seizure where the patient fell and experienced spasms.

While blood oxygen data is missing for the seizure on the 01.05.20, on the 18.05.20 there is a slight drop in SpO₂ around the time of the reported aura (figure 6), although in this case, the drop is not as drastic as the one in figure 5.

On one day the patient's spouse reported that a seizure likely occurred, as the subject was found deep asleep, with a low temperature and disorientated. The timeframe when the seizure might have occurred was likely between 15:00 and 17:45 (figure 7). There seems to be a steady decrease in heart rate starting at the time the seizure could have occurred.

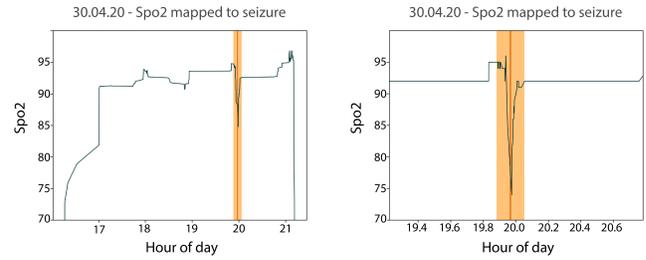


Fig. 5: The data collection for blood oxygen was sparse but in the smoothed overview (left) a drop in blood oxygen during the seizure on 30.04.2020 can be seen. In the detailed view on the right side the drop is more visible. The blood oxygen decreases from 96% to 74% in a matter of 3 minutes.

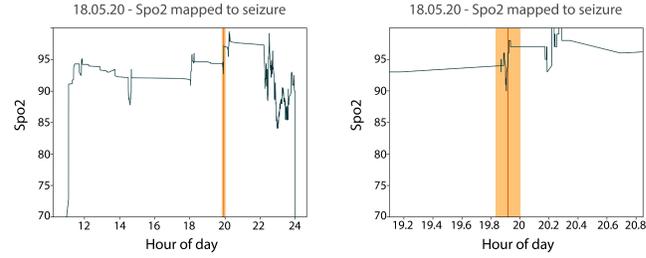


Fig. 6: During the aura which was reported on the 18.05.2020 at 19:56 the blood oxygen dropped from 96 % to 90 % and then increases to 98% shortly after. The smoothed overview on the left shows several short drops and spikes. In the detailed view on the right the drop can be seen more clearly.

The blood oxygen drops from 97% to 85% around 16:00 and another drop at 17:30 (from 94% to 88%).

VI. DISCUSSION & FUTURE WORK

The results from the monitoring provide some insight into what is possible using smartwatches for data collection of people with epilepsy. Comparing the reading from the blood oxygen sensor, there seems to be a discrepancy between the patient and the control subject. The patient shows many SpO₂ values below 90%, while the control subject rarely had such a low blood oxygen level. As the study by the DAZ [14] claims, epilepsy dogs react to the drop in blood oxygen of the epileptic, even though the exact mechanism is still unknown. The gathered data seems to confirm that there is a relationship between blood oxygen level and epileptic seizures.

Mapping the seizures to the data provides other insights. One time the blood oxygen drops significantly (almost 20% in a matter of minutes) and exactly at that time a seizure was reported. This seems to indicate, that the blood oxygen can be used as an indicator for seizures. On the other hand, during the aura the blood oxygen is barely showing visible changes, possibly because the drops are usually connected to focal seizures and not auras. Unfortunately mapping the blood oxygen to only two incidents doesn't allow for any statistical analysis and the study should be repeated on a broader basis.

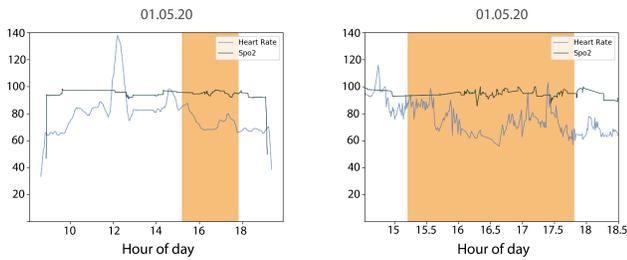


Fig. 7: Heart rate and SpO2 mapped to a time frame on 01.05.2020 where a seizure likely occurred. Smoothed on the left and a detailed view on the right.

The heart rate had spiked 40 bpm for one of the recorded seizures but previous research has already shown that it is not sufficient to look at heart rate alone for seizure detection. Not only does it drop during some epileptic seizures while it spikes in others, but it can be influenced too easily by other factors, which would lead to too many false alarms. During the aura though, it seems as the heart rate starts to lower roughly 30 minutes before the aura.

Ultimately, our research question cannot yet be answered definitely. The largest limitation in the study was the amount of data collected, due to three issues: 1) the data collection app occasionally stopped sending data due to stability issues on the subjects' devices. 2) the SpO2 sensor collects very little data throughout the day, so blood oxygen data is only available for a subset of seizure incidents. 3) a single subject and control each are insufficient to make any generalizable claims. Future research should use more patients and collect sufficient data to analyze using statistical methods. A more reliable device should also be used that sends SpO2 data continuously, though it still should be similar to a smartwatch which is non-intrusive and allows data collection in real-world scenarios. For validation, we also plan to compare sensors in future experiments with a calibrated medical pulse oximeter.

Whether seizures can actually be predicted is still an open question. Our data is currently too sparse to reliably determine whether the blood oxygen drops are preceding or following the seizure itself. Future work should extend our research to include more data types, such as HRV, accelerometer, physical activity level, or skin conductance. The Withings Move ECG smartwatch, as well as recent Apple watches, even include a sensor to produce an electrocardiogram [7]. More diverse data could lead to better insights about indicators for an imminent seizure. In any case, the ethics of such a prediction should also be explored in detail before implementing this feature, as an unexpected alert could possibly even act as a final trigger for the seizure itself.

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