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1. Introduction

SeizSmart is a work-in-progress mobile application for detecting, tracking, and reporting seizures in real-time. SeizSmart will implement a wearable seizure detection method using off the shelf smartwatch and smartphone technology, allowing users to notify emergency contacts when a seizure is in progress automatically.

Epilepsy is a neurological condition causing seizures, disruptions of the electrical communication between neurons. Epilepsy is characterized by sudden disturbances of perception or behavior caused by excessive neuroelectric activity. Figure 1 below shows the global impact of epilepsy. With more than fifty million people living with epilepsy globally, epilepsy is the fourth most common neurological disorder in the world after migraines, stroke, and Alzheimer's.

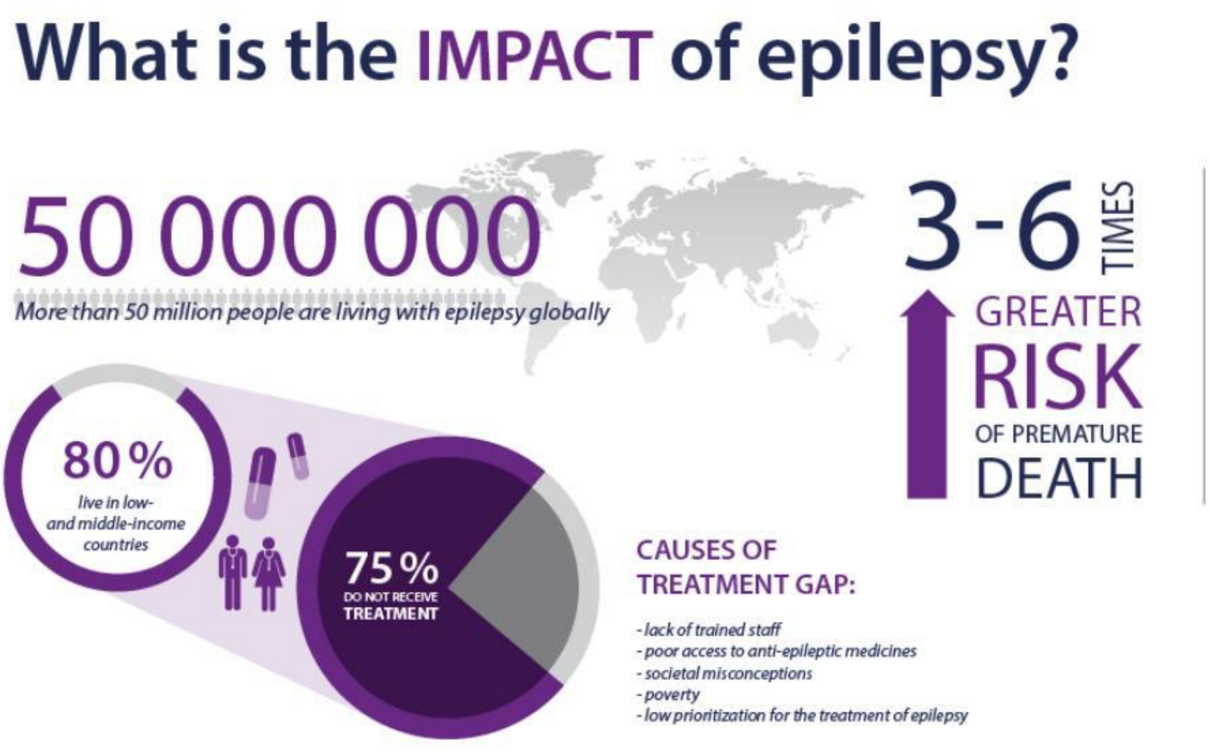

Figure 1: Impact of Epilepsy

A tonic-clonic seizure causes the patient's muscles to contract violently. The tonic-clonic seizure is the most infamous form of seizure and the kind that most attribute to seizures in general. According to the American Epilepsy Society, around 25% of persons with epilepsy experience tonic-clonic seizures in their life. These seizures can be especially dangerous to the patient, causing accidental injuries or even death.

Seizures come in three main phases, the preictal, the ictal, and postictal phases. The preictal phase is the time before the onset of a seizure. This phase significantly varies between patients. Some experience what is known as an aura, a simple partial seizure that can act as a warning sign for the patient. Other patients experience nausea, headaches, or other forms of discomfort for hours to a full day before the seizure with no indication of when the seizure will take place. Not every patient experiences something at this stage; for those patients, the onset of a seizure can come as a complete surprise.

The ictal phase is where the clinical seizure occurs. It's during this phase that the patient's body will start to go through distinguishable physical changes, shown on the following page in Figure 2. During this phase, the seizure will affect the patient's heart rate and rhythm. The most common heart rate pattern during a seizure is a steep acceleration at the onset of the seizure, followed by variations during and after the ictal phase. During a study on the cardiac effects of seizures, researchers found that the heart rate patterns during and after this phase were very similar in seizures from the same patient. This is also the phase where the patient experiences muscular convulsions during a grand-mal seizure. These convulsions provide another means for detection through rapid changes in acceleration.

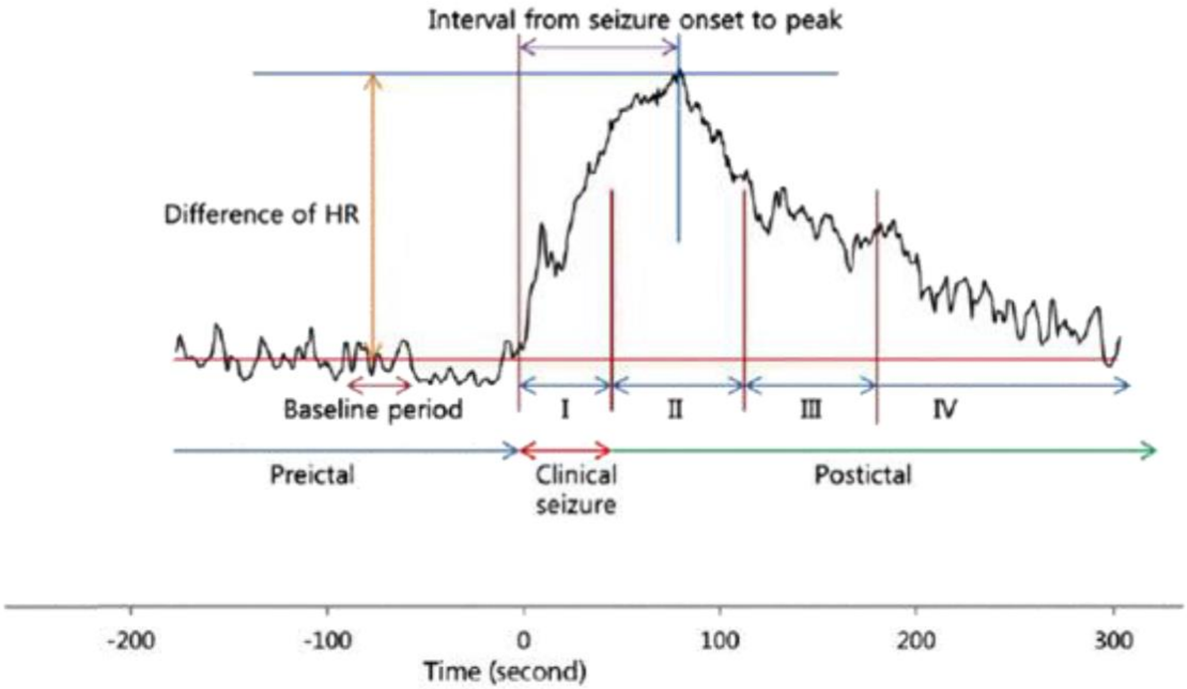

Figure 2: Variations in Heart Rate During The Phases of a Seizure

The postictal phase occurs directly after the seizure subsides, where the patient experiences an altered state of consciousness caused by neuronal exhaustion and hyper-inhibition. It is during this time that the brain recovers from the seizure. Symptoms of the postictal phase can present themselves as changes in behavior, mood, and physical health. At this point, the patient's convulsions have stopped, but the pattern in heart rate often still shows marked variations as it returns to baseline.

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Automated seizure detection outside of a well-equipped lab environment is a subject of increasing interest in recent decades. Figure 3 below shows the process flow for the current solutions to the problem. Current approaches use patient heart rate or motion data to detect when a seizure is in progress, but not both. Also, other methods of seizure detection are patient independent. What happens in a seizure differs between patients, but are usually stereotypic, meaning similar symptoms and behaviors tend to occur each time a unique patient has a seizure.

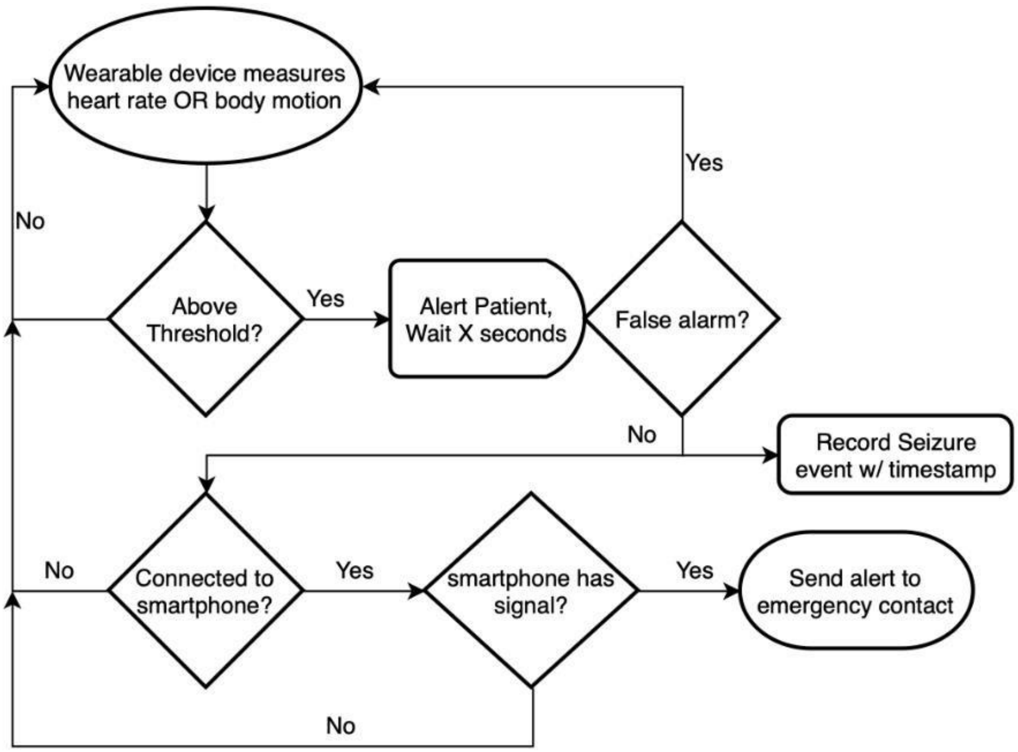

Figure 3: Current Process Flow

2. SeizSmart Product Description

SeizSmart is intended to be an application that uses a machine-learning algorithm to detect tonic-clonic seizures in real-time based on a combination of heart and motion data. It will use modern smartwatch technology to monitor the patient's biometrics, detect the onset of a tonic-clonic seizure, and directly notify the patient's emergency contacts.

2.1. Key Product Features and Capabilities

SeizSmart will utilize a patient-specific, multimetric approach to detecting seizures. The detection algorithm shown in Figure 4 below, is intended to distinguish when a patient is experiencing a tonic-clonic seizure from when they are not. It will be tailored to the individual patient's needs with a seizure profile, created by training a machine learning algorithm using biometric data collected on the patient's watch.

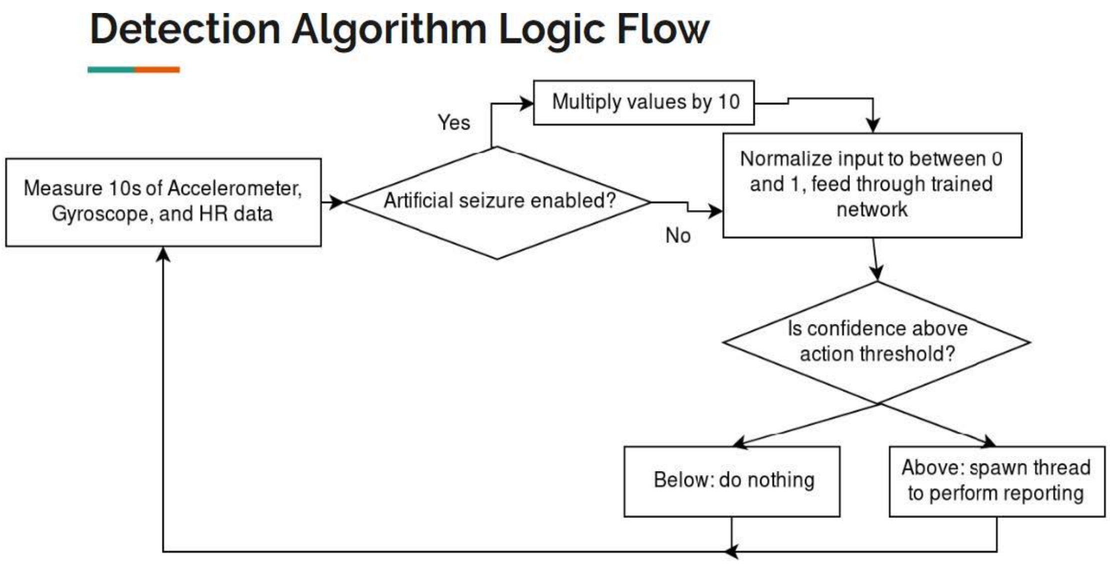

Figure 4: Detection Algorithm Logic Flow

The user will be able to adjust the sensitivity of the detection algorithm to suit their needs, favoring either false-positive or false-negative detection results. Some caretakers may prefer to err on the side of caution and increase the detection sensitivity. This preference will increase the probability of false-positives, notifying the emergency contact when nothing is wrong, but will also ensure that the caretaker is informed of every seizure. Conversely, the caretaker may find they are receiving too many notifications from false-positives and will want to decrease the detection sensitivity. This decrease runs the risk of missing more seizure events but diminishes the potential for "The Boy Who Cried Wolf" phenomenon, where real seizure events are ignored by the caretaker due to an overabundance of false ones. As more data is collected from the patient, both false-positive and false-negatives will gradually decrease as the detection accuracy increases.

Upon the detection of a seizure, SeizSmart will prompt the user, allowing them the opportunity to refute the detected result if they are not having a real seizure. This feature will prevent emergency contacts from being notified of every false positive. It will also be used to correct the erroneous seizure tag for the data surrounding the detection preventing similar patterns from resulting in false-positives in the future.

SeizSmart will provide means for a user to report an undetected seizure on the app. This report will be used to correct false-negative data for training purposes. The detection algorithm will reinspect the indicated time of the incident with a higher sensitivity to reconcile the user's estimate of the time the seizure occurred with the biometric data from that timeframe. This new information will improve the accuracy of the patient's seizure profile.

SeizSmart with record detected events into a log available to and manageable by the end-user. This feature will provide a semi-automatic way to track their seizure history. The log will contain the date and time the seizure took place, and the available sensor data for that period. only data related to seizure events will be permanently kept on the device to limit storage requirements for the device. The data will be pruned on the device after it has been pushed to the MySQL database, as shown in Figure 5. The log can be used by the patient and their caretaker to recognize broader trends and changes in the patient's epilepsy. This information could help narrow down possible seizure triggers for the patients. The information may also bring attention to changes in how frequently the seizures occur and how long the seizures, better informing the patient's physician of what action to take in the treatment.

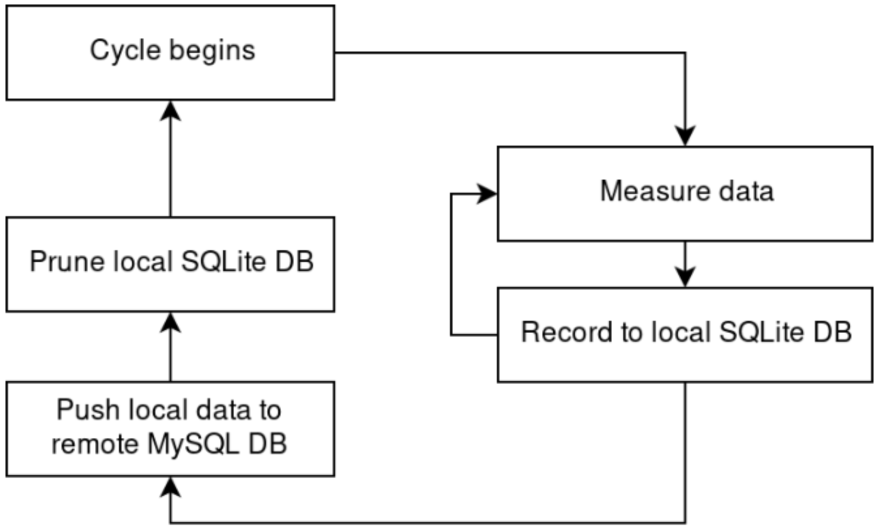

Figure 5: Recording Algorithm Flow

2.2. Major Components

SeizSmart consists of four major components, a smartwatch application, a smartphone application, A cloud server, and a machine learning algorithm.

2.2.1. Smartwatch Application and Database

An Android smartwatch application will monitor the patient's heart rate and motion metrics using the watches accelerometer, gyroscope, optical heart-rate sensors. It will also optionally collect environmental data from other available sensors. The watch will temporarily store these recordings locally using an SQLite database to be offloaded at a later time. While the watch application is running, it will analyze the data as it records, searching for patterns indicative of a tonic-clonic seizure.

When SeizSmart detects an ongoing seizure, it will notify the patient with an interactive alert on their watch. The notification will provide the patient with the opportunity to abort the alert if they aren't having a seizure. If the user does not abort, the watch will send a message to the patient's emergency contacts, informing them of the seizure.

2.2.2. Smartphone Application

The smartphone application will be used to configure account settings for the end-user. The application will also allow users to view a log of their past seizures with corresponding sensor data. From the seizure log, the user will have the capability to add seizures that were undetected by SeizSmart and remove seizures that were falsely detected, but not aborted in time.

From this smartphone application, the user will be able to set up and manage their personal settings. From here, the user will have access to settings such as their name, address, detection sensitivity, emergency contacts, and primary care physician contact.

2.2.3. Cloud Server and Machine Learning Algorithm

The cloud server will store user profiles for the end-user and data collected by the smartwatch application related to seizure detection. Data that was stored locally on the smartwatch will be offloaded to the cloud server's MySQL database. On the server, a TensorFlow neural network will train on the patient's biometric data to create their unique seizure profile. The updated seizure profile will be sent to the watch, so detection improves continually as more data is gathered.

SeizSmart's machine learning algorithm will take periods of accelerometer values, gyroscope values, optical heart rate values, and a boolean tag, signifying whether the data corresponds to a seizure, as inputs. It will use a gradient descent training algorithm. The training will be computationally expensive, so it must run on the cloud server. However, once the model is trained and sent to the smartwatch, the detection evaluation will be computationally simple, allowing the watch to detect seizures in real-time.

2.3. Identification of Case Study

SeizSmart is primarily for individuals who suffer from tonic-clonic seizures and their caregivers. In the future, the data collected by this application could also be used for research into understanding epilepsy better. SeizSmart will be a way to provide peace of mind to patients suffering from epilepsy, their families, and their friends. The patient will be at ease knowing that if they experience a tonic-clonic seizure, their emergency contact will be swiftly notified to check on them if they're injured.

In the future, data collected by SeizSmart could be used by researchers to understand better the patterns and environmental triggers related to seizures outside of a controlled lab. In addition, it may be possible for SeizSmart to detect other forms of seizures in the future. These seizures are often more subtle and don't have as distinct biometric markers, but with enough data, it still may be possible to distinguish them from nonseizure activity.

3. SeizSmart Prototype Description

The prototype for SeizSmart will consist of an Android watch app for seizure detection, an Android phone app for reporting, recording, and adjusting detection thresholds. It will also have a TensorFlow neural network to generate the detection algorithm. For the prototype, we will create a seizure data simulator that will generate data similar to what we might expect to see from patients using the watch using weighted random number generation.

3.1. Prototype Functional Goals and Objectives

The completed SeizSmart Prototype will have the ability to learn from simulated experimental data and send an alert to emergency contacts. A weighted random number generator will create data that roughly simulates the sensor values that would be typical of a patient with epilepsy. This data will be used to train our machine learning algorithm. The generated detection algorithm should be able to detect seizure events in simulated data that were not used in training. As more data is used to train the model, the accuracy of the detection algorithm should increase.

The prototype should also have an option to trigger the behavior corresponding to a seizure event manually. When triggered, the watch should issue an alert and start a ten-second countdown with an option to abort. If the abort option is selected, the alert should be canceled, and the data tagged as nonseizure. Else, if the alert is not aborted, the watch should send a message to the patient's emergency contacts, and the data should be tagged as a seizure.

3.2. Prototype Architecture (Hardware/Software)

The prototype hardware will include a smartwatch, a virtual server, a patient smartphone, and an emergency contact phone. The smartwatch must be equipped with enough storage for the Application and SQLite Database, a 4G cellular connection, a gyroscope, an accelerometer, and an optical heart-rate sensor. The virtual server must be on a network accessible by the smartwatch and the patient's smartphone. It will host a MySQL database and the machine learning algorithm. The patient's smartphone must have a 4G cellular connection and Bluetooth capabilities, while the emergency contact phone only needs the 4G connection.

The prototype software will have four main algorithms: the recording, reporting, detection, and machine learning algorithms. The recording algorithm will be used by SeizSmart to gather seizure-related data to be used in training. The algorithm will read the sensor values on the smartwatch and record them to a local SQLite Database. The local data will be pushed to the cloud server's MySQL Database on a daily basis. After the push has been verified, the SQLite database will be pruned to remove data not related to seizure events.

The reporting algorithm will notify the patient's emergency contact over a wifi or cellular network. When a seizure alert is not aborted by the patient, the watch will act as a medical alert bracelet, indicating the patient is epileptic and sounding an alarm. The watch will also check for a wifi or cellular connection; if one is available, it will send a notification to the patient's emergency contacts, alerting them of the patient's status and GPS location, if available.

The detection algorithm will distinguish when a patient is having a generalized seizure in real-time. The watch app will continuously gather ten-second intervals of sensor data. The sensor data for that period will be normalized and used as input into the trained neural network to create a confidence value. If the confidence value is above the threshold set by the user, it will trigger the reporting algorithm.

3.3. Prototype Features and Capabilities

The prototype will have most of the same capabilities as the final product. It will only include applications for Android phones and watches due to the cost and difficulty of iOS development. Also, the prototype will mostly use simulated data rather than real-world sensor data. Below in Table 1 is a comparison of the features that will be in the real world product vs. the prototype.

Functional elements	**Real-World Product**	**Prototype**
Detect generalized seizures in real-time	Fully Functional	Implemented through simulation
Record generalized seizures in real-time	Fully Functional	Implemented through simulation
Track generalized seizures in real-time	Fully Functional	Implemented through simulation
Monitor motion data	Fully Functional	Fully Functional
Continuously monitor the user's heart rate	Fully Functional	Fully Functional
Alert emergency contacts when the user does not respond	Fully Functional	Fully Functional
Collect data about the environment at the onset of seizure detection	Fully Functional	Fully Functional
Use machine learning to detect generalized seizures	Fully Functional	Implemented through simulation
functional without dependence on a smartphone or external device	Fully Functional	Fully Functional

Table 1: Prototype Features

3.4. Prototype Development Challenges

A major development challenge for this project will be time constraints. SeizSmart is a large project with multiple interacting components that all need to be developed and tested in only a couple of months. In addition, many team members are new to the multiple APIs used in the development of SeizSmart and will need time to become proficient with them.

4. Glossary

Absence Seizure: A generalized onset seizure that lasts only a few seconds, causing the patient to suffer lapses in awareness. Formerly known as a petit mal seizure.

Atonic Seizure: Also known as drop attacks. In this kind of seizure, some or all of the patient's muscles suddenly become limp.

Complex Partial Seizure: A brief seizure that starts in one side of the brain, also referred to as a focal (onset) impaired awareness seizure. During this kind of seizure, the patient loses awareness of their surroundings.

Clonic Seizure: A seizure characterized by sustained, rhythmic jerking of the patient's body.

Emergency Contact: Anyone who cares for a patient; usually family members.

Epilepsy: A neurological disorder characterized by multiple unpredictable seizures.

Myoclonic seizure: A seizure characterized by brief jerking or twitching of muscles.

Patient: An individual who experiences generalized seizures. May also be referred to as the end-user.

Seizure: A disturbance in the brain caused by a sudden surge in neuroelectric activity.

Seizure Profile: Personalized for each patient, describes information regarding the individual's typical seizure, such as physical indicators, or their average threshold for specific biometrics during a seizure. The seizure profile is used to provide more accurate seizure detection. Technically; a matrix of weights computed from training data used to classify new inputs as seizure or non-seizure related.

Simple Partial Seizure: A brief seizure that starts in one side of the brain, also referred to as a focal onset aware seizure. During this kind of seizure, the patient does not lose awareness of their surroundings.

Tonic Seizure: A seizure in which the patient's body, arms, or legs suddenly stiffen.

Tonic-Clonic Seizure: What most people think of when they hear the word "Seizure." It combines the characteristics of tonic and clonic seizures.

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