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# Early Detection of Migraine Attacks Based on Wearable Sensors - Experiences of Data Collection using Empatica E4

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## Abstract

The migraine is a chronic, incapacitating neurovascular disorder, characterized by attacks of severe headache and autonomic nervous system dysfunction, concerning 15% of people in developed countries. It is one of the most understated and incapacitating diseases in the world and costing yearly 111 Billion Euros in Europe only. In our study, we discarded the mechanisms affecting to the migraine but instead the focus was on early detection of the attacks by using human measured biosignals. By using a single, easy and comfortable wearable sensor device the aim was to develop a model that assists individuals to take their medication on time and hence help to avoid the pain in migraine. In this paper, a preliminary study concept is presented as well as the experiences of the data collection using Empatica E4 device is carried out. The experiences are introduced from the point of view of the researchers themselves but also the volunteers actually using the device answered to a short survey about the usability issues as well as gave opinions of the future migraine detection device itself.

## ACM Classification Keywords

H.1.2. [Information Systems]: User/Machine Systems; I.5.4. [Pattern recognition]: Applications; H.5.m. [Information Interfaces and Presentation]: Miscellaneous

## Author Keywords

Migraine; Wearable Sensors; Early Detection; User Study.

## Introduction

The migraine is one of the most understated and incapacitating diseases in the world. For example, the World Health Organization (WHO) has classified severe migraine attacks as among the most disabling illnesses, comparable to dementia, quadriplegia and active psychosis [15]. Migraine headache is usually associated with nausea, vomiting, or sensitivity to light, sound, or movement and when untreated, typically lasts 4 to 72 hours [10], [7]. The migraine condition starts in over 40% of the cases before 18 years of age, thus making it also a childhood disease [17].

The medication of migraine can be divided into two categories: preventive (daily dose) and acute medication (when symptoms start). The preventive medication is an expensive solution and especially with children, it is avoided as long as possible [17]. On the other hand, the problem with acute medication is that some people do not have early symptoms, some tend to easily dismiss the early symptoms, sometimes even on purpose. Thus the early diagnosis of migraine attack would be a valuable addition to treatment of the disease.

On the other hand, the wearable sensor market is currently one of the most rapidly growing area in consumer electronics. The global market for wearable sensors is estimated to reach \$34 billion by 2020 and to almost \$70 billion by 2025 [4, 18]. In research perspective, the sensor development has enabled that wearable sensors based recognition (activities, gestures, symptoms, diagnosis) to become one of the fastest developing areas of machine learning. The remarkable progress in the wearable sensor development including improved memory and battery properties has made

possible to measure human physiology 24/7, and more importantly with such accurate readings that have previously been possible only in laboratory settings.

In this article, a research concept aiming to early detection of migraine attack based on human biosignals collected with wearable sensors is presented with the emphasis on the experiences of data collection. The final study will be based on signal fusion (using biosignals like blood volume pulse, optical heart rate, temperature, acceleration and electrodermal activity), machine learning and especially to adaptive models, while every human and the migraine they are having, are different. In a long run, versatile analysis models are built above this data to help people to understand their own migraine better.

Although the migraine is widely studied the consideration has mainly been in neurological or in genetic aspects of the disease. Of perspective of wearable sensors, only a few approaches have been reported, like in [12, 13] where migraine attacks were tried to be predicted by using different combinations of SpO<sub>2</sub>, skin temperature, heart rate and electrodermal activity data. Despite of the promising results, the number of subjects is only two and the suggested solution might be quite difficult to adapt in practice. On the other hand, in [2], EEG (electroencephalography) band data was used to classify migraine episodes into categories of inter-ictal, pre-ictal, ictal and post-ictal. They approached the detection user-independently achieving over 60% accuracy while in [3], they discovered differences in EEG power and effective connectivity between patients and health controls as well as between different migraine stages. Moreover, the wearable sensor approaches for early diagnosis purposes include epileptic attacks prediction [5], sleep apnea [9] and to detect Parkinson disease [11].



Figure 1: Empatica E4

ID	DURATION OF DATA COLLECTION	DAYS ACHIEVED	MIGRAINE DAYS	DAYS MISSED
1	300	125	10	175
2	30	25	17	5
3	30	26	4	2
4	30	22	7	8
5	30	21	7	9
6	30	25	6	5
7	0	0	0	0
8	30	25	10	5
9	33	31	14	2
10	105	26	6	79
11	135	32	2	103

**Table 1:** Amount of data from test subjects as days. The missing days include days when the device was not worn but also days that the device did not work. With ID10 and ID11 the missing data is mainly caused by the device unreliability, skin problems and traveling without the device.

## Empatica E4

The development of sensors capable of measuring human physiology 24/7 and with accurate readings at home environment has enabled the drive in research world to different health solutions. While the heart rate has been measured since 1970s using chest straps etc. the new optical heart rate solutions have made possible to change the measurement locations to more convenient parts of human body and thus also affecting to the long-term measurement possibilities. On the other hand, wearable sensors including accelerometers and activity recognition studies based on them have increased rapidly since 2000 [8], and now also they are utilized within wearable sensor devices capable of measuring simultaneously several biosignals.

To be able to collect the long-term but real-time data for migraine detection Empatica E4 device (Figure 1) measuring blood volume pulse, heart rate optically, temperature, acceleration and electrodermal activity was selected [6]. The indication that these biosignals would enable the recognition of migraine was done based on the previous work by Pagan et al [12, 13]. An another important aspect also was that when using only single device the Empatica E4 is one of the most versatile devices available. The benefits of the device also included the cloud access to raw data and convenient watch-like design. The main disadvantage of the device is that it has to be charged and the data has to be uploaded to cloud almost every day presuming commitment from the volunteers collecting the data.

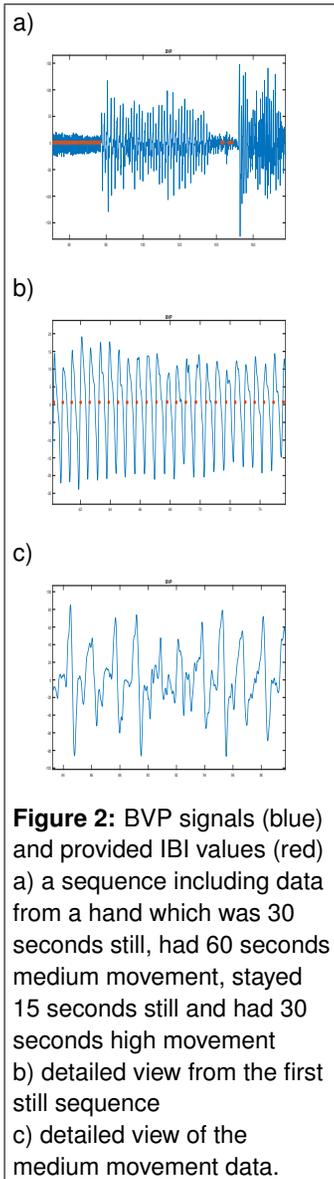
The actual sensors in the device include accelerometer, photoplethysmography (PPG), temperature and electrodermal activity sensors, all collected in the study. Photoplethysmography (PPG) sensor is used to measure blood volume pulse. A PPG is normally obtained by using a optical pulse oximeter which illuminates the skin and measures changes

in light absorption [16]. Blood volume pulse (BVP) can then be used to calculate heart rate and interbeat interval (IBI) which is the time interval between individual beats of the heart. With the algorithms provided by Empatica the IBI values were calculated automatically, decreasing the need for preprocessing. With accelerometer the movement of the object / limb it is attached can be measured. Empatica provided raw 3D acceleration with 32Hz using default range of  $\pm 2G$ . Skin temperature is measured with a infrared (IR) thermopile that detects the temperature difference between an IR absorber and a reference [14]. Electrodermal activity (EDA) depicts skin's electrical changes caused by sweating. EDA can be measured by using conductance but also other ways exists like skin potential or admittance. When sweat pores fill with sweat, the conductivity of skin increases. As the sweat secretion of skin is sympathetically controlled, sympathetic arousal can be detected as increasing skin conductance [1]. When using EDA, it has to be noted, that the skin temperature has a close connection with skin blood flow and changes in the skin temperature may also affect to electrodermal activity [1].

## Data Collection

To recruit suitable volunteers suffering from migraine the Finnish Society of Migraine was contacted and with their assistance several volunteers were achieved. In the first phase the population was limited to persons having migraine attack at least twice in a month just to speed up the data collection phase. Nevertheless, even with this way the data collection from a single volunteer took on average one to two months.

For every volunteer a half an hour personal guidance session was arranged to instruct them the use of the device. Every volunteer also filled during that session a form in which were asked their basic information (age, height,



**Figure 2:** BVP signals (blue) and provided IBI values (red) a) a sequence including data from a hand which was 30 seconds still, had 60 seconds medium movement, stayed 15 seconds still and had 30 seconds high movement b) detailed view from the first still sequence c) detailed view of the medium movement data.

weight), prodromal symptoms, description of their migraine and medication used. During the data collection every volunteer also filled a migraine diary but unlike in previous studies [12], [13] no pain curve was asked but instead the knowledge about the duration of migraine, its intensity (mild/average/hard) and the location of pain. In addition, other symptoms that appeared were described.

#### *Researcher experiences*

Due to the high price of the Empatica E4 devices only six devices were purchased for the project in the first step. With the help of the Finnish Society of Migraine the volunteer recruiting proceeded fluently and altogether 11 test subject were achieved in two phases fulfilling all the specifications. For every volunteer a username and password was provided to Empatica cloud and by using this user information the researchers were able to ensure from the cloud that data was actually uploaded. In problem cases, technical support was provided by the researchers. These problem cases included unsuccessful measurements, skin conditions (rash) and poor attachment of electrodes.

Every volunteer was asked to wear Empatica 24/7 excluding swimming, showering and sauna. In occurrence of migraine the volunteers marked the event start and end by pushing the device button and describing the symptoms to the diary. The data set achieved from the 11 test subject included 358 days of data and 83 migraine attacks. The more detailed information can be found a Table 1 on sidebar. The data was collected from a time span of 753 days, meaning that half the days were missed. From every individual subject the data was downloaded to the hard drives of the university at daily basis while every upload formed a zip-file of its own. With a long data collection periods a more convenient would have been to just download the data once after the whole data collection but the daily approach,

on the other hand, enabled us to see the malfunctioning problems (i.e. empty files) in real time.

When considering the overall device reliability, the problems occurred mainly after a month of device use. With 7 cases of 10 there were no major problems but when sending the same devices for next volunteers there were several cases where the data files uploaded were empty. The support of Empatica explained that the empty files were caused by a firmware problem. The firmware update has been provided in May 2017 but a new data collection period of several months will be needed to ensure that the reliability issues are solved. Moreover, one of the devices never returned from a volunteer nor any data were achieved regardless of several contacts made.

On the other hand, when considering the actual data achieved the biggest concern was noticed to be the day time signal quality. As the device specifications promised a continuous heart rate, they stated that the studies with strong movement (more than 30% of time) do not provide reliable IBI values. To test the effect of movement a short test was performed with a comfortable tightness of the device on the wrist. The subject was asked to sit and to perform a sequence constituting of 30 seconds data without any movement, 60 seconds with medium hand movement (i.e. sitting and moving only the hand where the device was at walking pace), 15 seconds without movement and 30 seconds high movement (moving the hand with running pace). In Figure 2 of sidebar it can be seen that the IBI data is provided by Empatica only from the parts of sequence when there were no movement and moreover, with this sequence the still data also after the movement contains only a few IBI values. Thus it was not surprising that while the measurements for migraine study were done continuously including data from 24 hours in a day, there were long intervals of

### What was good in the device?

Easiness of first time use: 6  
Convenience: 2  
Easy to remember: 0  
Downloading of data: 4  
Recharging: 3  
Appearance: 1  
LED light: 1  
Button: 0

### What properties of the device caused most problems?

Daily recharging: 3  
Daily downloading: 4  
Size of the device: 0  
Skin irritation: 2  
Inconvenience: 0  
Pushing the button: 1  
Nothing; 1 Something else, what : 3  
- Device malfunctioning  
- Correcting the error of pushing the button in wrong time  
- Putting the device on after recharging

**Table 2:** User experience survey answers

missing IBI data on day time making the sleep time data more usable in the study.

### Volunteer experiences

To study the experiences of the volunteer a short survey was performed with an answer rate of 64 percent. The survey was divided into two sections: 1) considering the data collection period, and 2) about the volunteer opinions of a wearable sensor device applicable for migraine detection.

From the perspective of the data collection the most interesting aspect was that all the users would volunteer again to the study. Of course, when taken into account that only one of the answerers had the device in use more than two months it can be biased that way that the ones actually having problems with the device did not want to take part in the survey. In actual usage of the device the answerers either reported having no trouble, slight trouble or moderate trouble while the most positive feedback was given to the easiness of first time use and to the way that data were uploaded to cloud and how to recharge the device. Nevertheless, the daily upload and charging were the most negative aspects of the device. The distribution of the feedback can be seen as Table 2 from the sidebar.

When asking questions about the future device the optimal location was considered to be wrist, although the finger and chest locations were also mentioned while the actual device could be a watch, ring, skin patch or jewelery. The battery duration was simply chosen to be between 3 and 7 days. From commercial point of view, the price between 100 and 200 Euros was considered as a price that all the users would be ready purchase the product.

### Conclusion

The more the wearable sensors development has made possible to measure human biosignals 24/7 the more health

related application areas there are where they can be utilized. In this study, the application area was chosen to be migraine, one of the most expensive diseases to the society. The early detection of migraine was noticed to be a fruitful ground while targeting to an actual disease the volunteers actually committed to the study. When considering the Empatica E4 device itself some disadvantages existed. If the reliability and the day time signal quality issues will be fixed the device and its characteristics would be of high interest in our further data collections.

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