Tachycardia, Diagnosis tools, and Accessibility

Discipline: Biomedical Engineering

Research Question:
What is the effectiveness of a low-cost tachycardia (high heart rate) diagnostic tool in underdeveloped Louisville?

Approach: To Determine
Design: Experimental
Method: True Experimental Quantitative Method
Data Source: Secondary
Method Design Statement:
The effectiveness of a self-built, easily accessible Tachycardia diagnosis tool was determined using pre-collected consensus data from MIT. Data from this census regarding undeveloped Louisville was inputted into the device to see when a 15% spike in the heart was found, the user would be alerted to take note of this problem. The effectuvness (number of times user was alerted) was quantified and compared to the control of regular diagnostic tools.

Keywords:
Tachycardia, diagnostic tools, accessibility, cost, effectiveness, socioeconomic status, pacemaker, photoplethysmography

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Abstract

In America alone over 600,000 people either suffer from high heart rate (tachycardia) or low heart rate (Bradycardia). The biggest cause of this problem is the lack of affordable diagnostic tools. Therefore, this research aims to develop an affordable device that is able to diagnose abnormal heart rate. The device will be portable, effective, low-cost and easy to use. Thus, solving back for a problem that continues to plague the US.

In order to ensure accessibility and feasibility, the device will work in a simplistic manner. First, the device establishes a baseline heart rate for three times of day; morning, afternoon, and evening. Then, heart rate values are taken every 30 seconds, and when a 15% increase or decrease in heart rate compared to the corresponding baseline is detected, a notification is sent to the user warning them their heart rate is reaching abnormal levels.

The device was tested 300 times with heart rate values supplied by the MIT arrhythmia database. The success rate for the app as a whole is 93.34% and when adding and subtracting the margin of error (4%) the result is 89.34% to 97.34%, meaning that for 89.34% to 97.34% of the entire population of individuals suffering from abnormal heart rate, the device will be successful. Overall, the engineering goal was achieved. The total cost of the device is $28 (low-cost), the device is portable and easy to use, and is effective with an overall success rate of 93.34%.

Introduction/Literature Review

Tachycardia and Bradycardia are two of the deadliest and most widespread cardiovascular diseases on the planet. There are over 600,000 people that suffer from these diseases in America alone (Badhwar, 2008). As this problem continues to grow, it has become more apparent that it is concentrated on a specific group of individuals: low-income individuals living in the US who do not have the money to purchase expensive diagnostic devices (Harvard Medical School, 2015). The situation isn't getting any better, however; companies responsible for producing diagnostic tools have been steadily increasing the prices of cardiovascular diagnostic tools. As a result, individuals suffering from these diseases have been forced to accept these outrageous prices in order to stay alive. The problem has gotten so far out of hand, that some individuals choose not to utilize diagnostic devices in order to avoid the debt trap (American Heart Association, 2017).

This problem has not gone unnoticed, however; newspapers, academic journals, and even magazines around the country have started to cover the problem and spread awareness. However, there has not been a feasible, effective solution to resolve this problem. Many startup companies try to develop diagnostic tools that are affordable and effective, but almost none of them work (MedTech, 2018). The reason is simple: there is a tradeoff between accessibility (cost) and effectiveness. As cost goes down the effectiveness goes down as well, and as cost goes up the effectiveness goes up (Lerman, 2015). This is because the only way for companies to generate enough revenue is by placing high prices for the "effective" devices that they are putting out.

Let's take the recent start-up company, Holter, as an example. Holter is a start-up company that aims to resolve this exact issue: developing cardiovascular diagnostic tools that are not only effective but easily accessible as well. However, this start-up was unable to complete the mission, as their device had so many drawbacks. The device is super expensive, the lifespan of the device is severely limited, and the device isn't even effective (Hopkins Medicine, 2017).

That is not the only problem, however. Devices have been being creating for so many cardiovascular diseases, except for tachycardia (Owens, 2018). Doctors are currently looking at how tachycardia occurs, what the effects of tachycardia is, and how to cure tachycardia has a whole. No one has taken a step back, analyzed the situation and tried to attack the problem at the root cause so that it never occurs in the future (Medical Health, 2014). Thus, developing an effective, easily accessible tachycardia diagnostic tool becomes the biggest problem.

There are four prongs that help develop the overall gap in the research. Modern cardiovascular diagnostic tools have four key problems: they are far too expensive for the average consumer to afford, they require a trained physician making it less accessible to individuals in underdeveloped areas, most of the diagnostic tools are invasive to the human body, and none of these tools have been tailored specifically to the needs of someone suffering from tachycardia. Thus, the following research question was developed: What is the effectiveness of a low-cost Tachycardia diagnostic tool in underdeveloped Louisville? By targeting a specific population, underdeveloped Louisville, the value of the research grew, and the scope got narrower making it more feasible.

Tachycardia

Before targeting the problem at the root cause, a simple understanding of the disease is necessary. If your heart rate is too high, chances are that you will be diagnosed with something called Tachycardia, which is a term used to signify that your heart is beating at an abnormal pace, when diagnosed with Tachycardia your heart may not be pumping an enough blood to your body. When diagnosed with this you can experience a wide number of symptoms including; shortness of breath, light headedness, and heart palpitations (Mayo clinic, 2016).

When diagnosed with supraventricular tachycardia, electrical signals in the heart's upper chambers fire abnormally (American Heart Association, 2018). This interferes with electrical impulses coming from the sinoatrial (SA) node, the heart's natural pacemaker. The disruption results in a faster than normal heart rate. This rapid heartbeat keeps the heart's chambers from filling completely between contractions, which compromises blood flow to the rest of the body.

The disease is typically noticed among children, women, anxious young people, and people who are physically fatigued. These are all individuals that fall into the category of low-income, and are therefore living in the most precarious, undesirable, and vulnerable situations (American Heart Association, 2018). Therefore, it is more imperative that a low-cost, portable, effective, and easy to use tachycardia diagnostic tool is developed to help these individuals.

Thousands of people in the United states suffer from this disease and it is typically diagnosed when the heart rate is above 100 bpm (beats per minute). Many people are able to receive treatment to help combat this disease and avoid some of the symptoms, but due to cost issues some people are unable to receive access to these treatments. That is why many people have turned to attacking the problem at the root cause via diagnostic tools. Unfortunately, another problem arises: people are unable to access these diagnostic tools either. They are unable to purchase treatment, they are unable to purchase a diagnostic tool, so they are no unaware of when the symptoms will arise, and unsure of how to treat these symptoms without getting severely hurt.

Method

This project utilized a quantitative approach along with an engineering method to create and test the effectiveness of the device. In short, the effectiveness of a self-built, easily accessible Tachycardia diagnostic tool was determined using pre-collected consensus data from the MIT cardiovascular database. To develop a more feasible scope, underdeveloped Louisville (the area with the highest crime rates and closest to the downtown area) data points were utilized.

Using this methodology, data points from the MIT database were inputted manually into the device to see when a 15% spike in the heart was found, the user would be alerted to take note of this problem. When the heart rate was above 15% and a notification as sent then the trail was considered a success. Conversely, when the heart rate was above 15% and a notification was not sent then the trial was considered a failure. After the trials were conducted, an overall success rate was gathered by taking the number of success and dividing it by the number of trials.

This use of this methodology can be justified in a really simplistic manner. By utilizing a true quantitative methodology, data gathered from the publicly available MIT arrhythmia database was able to be manipulated in a manner to gather new data (Babbi, 18). Since, heart rate values from patients were unable to be gathered, the MIT database became really important for this project. If a different methodology were used that the data from the MIT database could not have been manipulated in a manner to gather secondary data.

Development of the Device

Once a basic understanding of the problem has been understood, it is important to understand what the “device” really is, how it functions, how much it costs, and how it will be built.

The device that is being built to resolve this problem requires a significant amount of materials. First off, an Arduino MKR Zero microcontroller. This microcontroller used acted as the “motherboard” of the device, in that without this microcontroller there would be nothing to even execute the program. This microcontroller was used in order to make the device more user friendly and feasible. The size of the microcontroller ensured that the device would have the ability to be tailored to the people who need it most and was able to be implemented into the society.

When developing this device, it was found that the microcontroller did not have enough voltage point and ground ports for all the sensors and modules to operate properly. Because of this, 4 by 4 pin breadboards were needed to allow the energy to flow through the board allowing the microcontroller to have multiple voltage and ground points (Vilkomir, 2016). In order to maintain the structural integrity and stability of the device, the breadboards were super glued down to the board. Once the breadboards are in place the Bluetooth module must be attached. The Bluetooth module allowed for a smooth and effective transition of data from the motherboard to the application, where all the data is being held.

Once the Bluetooth module has been attached all that has to be done is converting the charges and plug it into a couple of voltage and ground ports to get it functioning. After the Bluetooth module was attached, a photoplethysmographic heart rate sensor must be purchased in order to ensure the best most effective heart rate readings. Photoplethysmography is one of the most effective methods of gathering heart rate values. It requires a bright green led light that can be seen on the back of basically any smart watch (Intermountain Medical Center, 2016). This allows the blood density to be calculate by determining the reflection of the light putting out the most accurate heart rate reading.

The last component that had to be attached is the power source, however that is attached at the very end so that the battery would not be drained A laptop that had android studio and the android IDE is needed, so that the application can be programmed. In order to ensure that the program is functioning correctly and effectively, an android device is needed to gather multiple data points.

Coding the device

Once the device was developed, the program for the device along with the android application, which acted as the user-end interface had to be developed. In order to code the program for the device to function properly the Arduino IDE. By utilizing the Arduino IDE opposed to any other software language, the effectiveness of the device was maintained. The device was compatible with this software language, and the blue tooth module was able to work effectively with this language.

The long code was developed on the Arduino IDE and on the android studio program. The module was set to a pairable device and connected with the device. Then in order to get the heart rate signals, the application had to publish Bluetooth capabilities. In order for this to occur, the application on Android studio was altered. After this, the Arduino program was set to receive signals from the heart rate sensor every 10 seconds.

Once the program for the device was developed, the application which acted as the interface for the user had to been developed. As mentioned earlier, this application was programmed on the android studio platform which utilized the Java programming language. This language was used in order to maintain compatible with the microcontroller and the Bluetooth module. The application that was developed, enables the user to not only view their current heart rate, but also view how their heart rate has been progressing over the past couple of days. This is also the place where the user will be able to view the notifications regarding their abnormally high or low heart rate. More importantly, a screen which allowed data to be manually inputted was incorporated into this device. Without this screen, no data would have been able to be gathered.

Sample size

Once the device had been developed, the device had been coded, and the application had been developed the sample size had to be decided on. The sample size is the number of trials that were tested in order to get an overall effectiveness of the device. At first a sample of size of 500 wanted to be utilized, however in order to gather all of the data points in a reasonable time frame, a sample size of 300 was utilized.

This sample size had a margin of error of 4%, essentially meaning that when an overall effectiveness of the device had been gathered and statistical analysis was applied there would be a 4% plus or minus factor with the overall success rate.

Results and Discussion

After successful engineering of the device, the communications portions could be implemented. This portion was entirely software based and utilized Bluetooth connectivity between the arduino uno MKR mini and an external android application. The arduino uno MKR mini gathers heart rate values and wirelessly sends them to the android application. Using those heart rate values, a baseline (average) heart rate is established. After the baseline is established, heart rate values are taken every 15 seconds and compared to the baseline. Once a 15% decrease or increase in heart rate is noticed an SMS message (notification) should be sent to the device explaining the significant spike in heart rate. The threshold was set at 15% because a 15% increase or decrease in the baseline is considered to be abnormal (Badhwar, 2008). Figure 1 displays a detailed flow of the software.

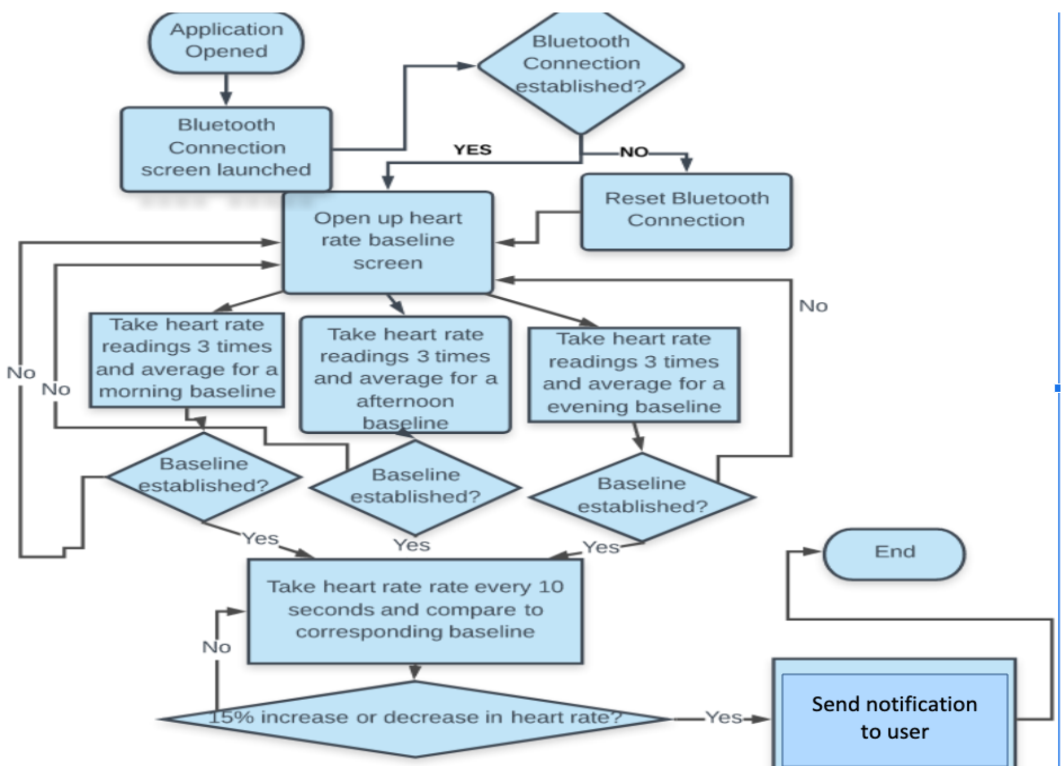

Figure 1 “Device functionality flowchart”

This flowchart explains, in detail, how the device is supposed to function and how the end goal is reached

After successful engineering and programming of the device, the accuracy of the device was determined. Please refer to the methods section for a detailed explanation for how the procedure was carried out. After all 300 trials were completed, an overall success rate for each of

Baseline	Heart rate	Notification sent?	Proved prediction right?
75	80	NO	YES
75	79	NO	YES
75	78	NO	YES
75	77	NO	YES
75	76	NO	YES
75	75	NO	YES
75	74	NO	YES
75	73	NO	YES
75	72	NO	YES
75	71	NO	YES
75	70	NO	YES
75	69	NO	YES
75	68	NO	YES
75	67	NO	YES
75	66	NO	YES
75	65	NO	YES
75	64	NO	YES
75	63	YES	YES
75	62	YES	YES
75	61	YES	YES
75	60	NO	NO
75	59	YES	YES
75	58	YES	YES
75	57	YES	YES
75	56	YES	YES
75	55	YES	YES
75	54	YES	YES
75	53	YES	YES
75	52	YES	YES
75	51	YES	YES

the conditions (abnormally high and abnormally low) was calculated. Figures 2 and 3 show an example 30 data sets for each condition.

Figure 2 "30 data sets for abnormally low heart rate"
This figure shows 30 data sets with steadily decreasing heart rate value and a baseline of 75. If the heart rate is 15% lower than 75 a notification should be sent to the user, proving the prediction correct.

Baseline	Heart Rate	Notification sent?	Proved prediction right?
75	70	YES	NO
75	71	NO	YES
75	72	NO	YES
75	73	NO	YES
75	74	NO	YES
75	75	NO	YES
75	76	NO	YES
75	77	NO	YES
75	78	NO	YES
75	79	NO	YES
75	80	NO	YES
75	81	NO	YES
75	82	NO	YES
75	83	NO	YES
75	84	NO	NO
75	85	NO	YES
75	86	NO	YES
75	87	YES	YES
75	88	YES	YES
75	89	YES	YES
75	90	NO	NO
75	91	YES	YES
75	92	YES	YES
75	93	YES	YES
75	94	YES	YES
75	95	YES	YES
75	96	YES	YES
75	97	YES	YES
75	98	YES	YES
75	99	YES	YES

Figure 3 "30 data sets for abnormally high heart rate"
This figure shows 30 data sets with steadily increasing heart rate value and a baseline of 75. If the heart rate is 15% higher than 75 a notification should be sent to the user, proving the prediction correct.

Based on the data, for the majority of instances for which the heart rate values were 15% higher or lower than 75 a notification was sent, resulting in a successful trial and increasing the success rate. Moreover, for majority of the instances for which the heart rate values were not 15% higher or lower than 75 a notification was not sent, thereby creating a successful trial and increasing the success rate. However, this was not the case for every data set. For example, looking at figure 3 when the heart rate value is 70, which is not 15% less or more than 75, a notification was sent which was not supposed to occur.

Since the device was not effective 100% of the time, a more accurate success rate had to be determined. This was done by counting the number of times the prediction was proved correct and dividing it by the total number of data sets. The final quantitative value of the success rates along with a graphical representation of the success rates can be seen in figures 4 and 5.

Abnormally high heart rate	Abnormally low heart rate	Overall effectiveness
90%	96.67%	93.34%

Figure 4 "Success rate values"
This figure shows the quantitative success rate of the device when the heart rate is abnormally low or high

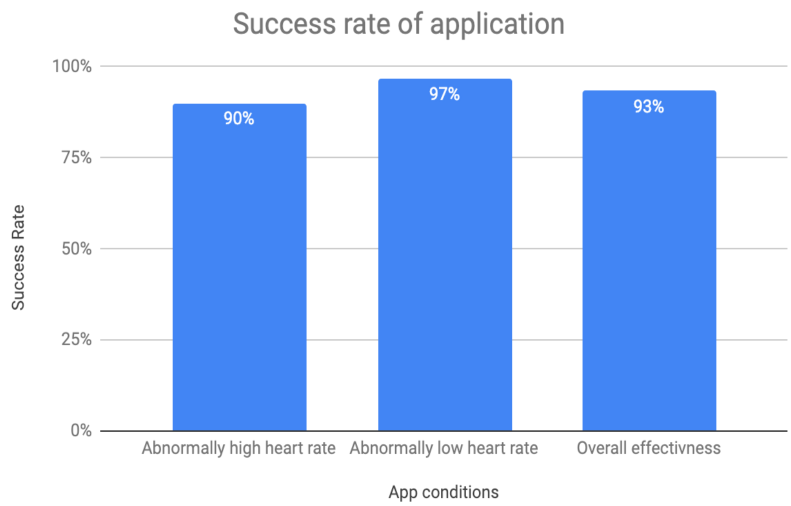

Figure 5 “Graphical representation of success rate value”
This figure shows a graphical representation of the success rate when the heart rate is abnormally low or high.

The device had an overall success rate of 93.34% with a success rate of 90% when the heart rate values were abnormally high, and a 96.67% success rate for when the heart rate values were abnormally low. This means that the device had an overall false positive rate of 6.66%. This false negative value was calculated by taking the overall device success rate (93.34%) and subtracting that from the ideal success rate (100%). A false negative is defined as a test result that indicates that an individual does not have a specific condition, when in reality they do (Melina, 2010). More specifically, in the case of this research a false negative is defined as a test result indicating that an individual does not have abnormally high or low heart rate when in reality they do. However, the device is still immensely effective at 93.34%.

The above success rates shown are only applicable to the 300 data sets collected. In order to apply them to the entire population of individuals suffering from abnormal heart rate in the United States a confidence interval formula must be used (refer to figure 6 for formula). This confidence interval formula where P is the success rate, n is the sample size, and the Z critical value is the confidence interval can be applied to determine the overall success rate across the United States, not only for the 300 data sets (Hand, 2015).

$$\hat{p} \pm (z \text{ critical value}) \sqrt{\frac{\hat{p}(1 - \hat{p})}{n}}$$

Figure 6: "Confidence Interval formula"
This confidence interval formula allowed the overall success rate of the device for the 300 data sets tested, to be extrapolated and receive an overall success rate of the device for the entire population of individuals across the US suffering with abnormal heart rate.

Using the formula shown in figure 6, and implementing the overall success rate (93.34%), a standard confidence interval and its corresponding Z critical value (95% and 1.96, respectively), and the sample size (300) a success rate proportion will be developed. After applying the formula the success rate proportion is between 89.27% and 97.41%. This means that the device will function properly 89.27% to 97.41% of the times tested for every user in the United States, with 95% confidence.

Not only was the device effective, but it was also low cost when compared to other treatments and diagnostic tools. One of the most commonly used treatments of abnormal heart rate, the pacemaker, costs $19,000 without insurance and when accounting for the cost of surgery and hospital stays the device costs $96,000 without insurance (Lee, 2014). Fortunately, the device created was able to significantly decrease the cost, making it immensely easier for the average individual at risk for abnormal heart rate to be treated. Figure 7 displays the cost outline and overall cost of the device developed.

Total Cost	
$28	
$11	Arduino Uno mini
$5	Bluetooth Module
$4	Heart Rate Sensor
$2	Breadboards
$4	Power source
$2	Wires

Figure 7 “Cost outline and total cost of production for device”
The figure above displays the cost breakdown (cost of the materials used) and the overall cost of the device developed. The grand total cost of production for the device was $28.

The total cost of production for the device is $28. As mentioned earlier, this is significantly cheaper and more affordable than comparable devices of $19,000. As many individuals at risk of heart diseases and abnormal heart rate live in deplorable areas and are on the lower end of the socio-economic status spectrum, it is crucial to have a device that is affordable (Shishehbor, 2006). In addition, the device had an overall success rate of 93.34%, only further validating its superiority when compared to other devices that attack the same problem.

Conclusion

New Understanding

The device developed successfully met the engineering goal by effectively detecting abnormal heart rate values and sending notifications to the user 93.34% of the time when a 15% spike in heart rate was noticed. The results suggest that the device developed through this research is an effective, non-invasive, easy to use, portable device, creating the new understanding. This device effectively combats the flaws of other treatments and diagnostic tools, further building up the new understanding and achieving the engineering goal.

There is currently a gap between socio-economic status and the rate of cardiovascular deaths. The reason for the immense amount of cardiovascular deaths is due to the lack of effective, portable, affordable, and easy to use tachycardia diagnostic tools. Fortunately, this research bridges that gap by developing an affordable, portable, effective, and easy to use tachycardia diagnostic tool that has the ability to be used by low-income individuals, and individuals who are on the lower end of the socio-economic status.

	Device Built	Pacemaker	Electrocardiogram (ECG)
Cost	$28	$19,000-$96,000	$175 per test
Accuracy of diagnosis	93.34%	81%	68%
Non-invasive	Yes	No	Yes
Easy to use	Yes	No	No
Portable	Yes	No	No
Used independently	Yes	No	No

Figure 8 "Flaws of other devices"
The above figure demonstrates the problems associated with current cardiovascular treatments and diagnostic tools, as well as how the device developed through this research resolves these flaws.

Contextualization/Implications

The device developed through this research is 678.6 times cheaper and 12.34% more effective than the pacemaker. Moreover, while the pacemaker is invasive to the human body (surgery is required to get the device functioning properly) this device is not invasive to the human body, making it a lot more accessible to people who suffer from abnormal heart rate. In addition, other devices are difficult to use and require a trained physician in order to be effective. Unlike this, the device fills that gap by providing a user-friendly, easy to use interface that can be used without a trained physician, thus, dramatically increasing the accessibility.

The media has been focusing an immense amount of time on abnormal heart rate, however, the solutions that aim to solve back for abnormally high and low heart rate are flawed in many ways. This device serves as a remedy to all the flaws associated with other devices, therefore filling the gap between socio-economic status and rate of heart diseases.

Limitations

While this device is a huge step up from comparable devices, there are some limitations that stunt the validity of this device. Primarily, the user-friendliness of the device is limited. This is because the device is currently unorganized with a bunch of loose-wires, making it hard to be implemented into the real world. Secondarily, the device has only been tested 300 times which means that the margin of error associated with the success rate is relatively large. Furthermore, because of this margin of error, when statistical analysis' are performed on this data the resulting values could be skewed. Finally, this device can only be used during regular day to day activities, and not in conditions in which physical exercise is exerted. This is because when exercising, heart rate can increase at a great pace.

Future Directions

The next steps for this research stems from the limitations of the device. The first next step would be to test the device on a larger scale with upwards of 1000 heart rate values to decrease the margin of error associated with the success rate. Once the effectiveness of the device is tested on a larger scale, the user-friendliness must be enhanced. This can be done by making the device wearable and miniaturizing the arduino UNO MKR zero to make the device more feasible. Finally, taking the process of solving back for abnormal heart rate to the next level. This can be done by allowing the user to contact their physician once their heart rate has experienced a 15% spike in heart rate. Once these three directions are implemented, this device will have the ability to save the lives of millions.

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