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A prototype of an ECG signal-monitoring device convenient for at-home usage, portable, reliable, and tailored specifically to an older population suffering from loneliness (age ≥ 65 years) that is possibly suffering from risk factors, allowing improvements in accuracy and cost efficiency.

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ABSTRACT
Existing at-home devices that detect ECG signals expand their potential users to all patients who are significant victims of mainstream risk factors like hypertension, lifestyle, and age. While it is true that the same device is useful to all patients with risk factors, this broad audience affects the accuracy. Predominantly unaccounted factors like loneliness, depression, stress, and/or a combination of these symptoms also contribute to the risk of cardiovascular diseases. Our team has formulated that using this particular device only on a specific group, for example, a lonely, old aged, and possibly depressed population having almost every symptom in common, could elevate the accuracy. The application of the EXG Pill in a prototype can lead to early and accurate ECG recordings, specifically targeting individuals aged 65 and above in 24/7 care settings, such as old age homes and geriatric centers where immediate medical assistance may be unavailable. To assess the authenticity of this and establish a novelty, we ran an on-patient test using the semi-built prototype in addition to an emotional evaluation survey on each of the subjects to corroborate the effect of overlooked factors when used in a non-conventional settings such as, at home or at centers that shelter patients. After performing and critically analyzing the whole research tests and surveys, we came to the conclusion that Loneliness, along with Hypertension and Obesity, is a prominent risk factor impacting the probability of developing a stroke, cardiac arrest, or any other kind of heart malfunctioning.

I. INTRODUCTION

Predicted to reach nearly 23.3 million deaths by 2030 [1], Cardiovascular Diseases are caused due to abnormalities in functions of the heart and the blood vessels. These abnormalities are often accompanied by one or more risk factors including but not limited to hypertension, diabetes, obesity, lifestyle, habits, genetic factors, stress, depression, and even loneliness. CVDs have invariably been affecting people regardless of their display of symptoms. Hypertension, which puts an inflated workload on the heart, causes changes like Hypertrophy (enlargement) of the left ventricle and can ultimately end in Heart failure. High blood pressure is also a significant risk factor for cardiovascular diseases. It is found with the help of various RCT (Randomized control trials) that having a lower BP is extremely effective for CVD prevention, which is <120 mm Hg in old aged people. It varies in different genders, ages, and ethnicities.

Delving into statistics of the people suffering from such diseases all over the world, it can be safely concluded that an older population (age ≥ 65) possesses a high rate of being affected by CVDs or factors leading toward CVDs.

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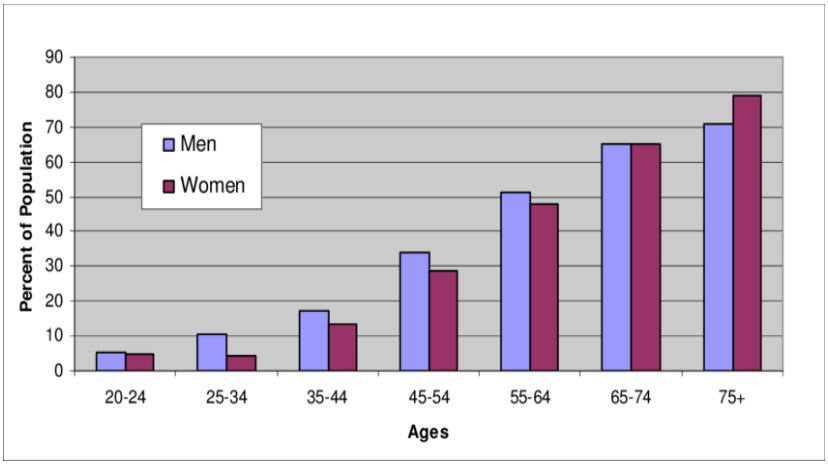

Prevalence of cardiovascular diseases among American adults by sex and age [3]

The most common aging change is the increased stiffness of the large arteries, called Arteriosclerosis, or hardening of the arteries. Age can cause other changes to the heart, as abnormalities in the electrical system can lead to Arrhythmias: a rapid, slowed, or irregular heartbeat; The chambers of the heart may increase in size, which can increase the risk of Atrial fibrillation: a common heart rhythm problem in older people; With proceeding age, people may become more sensitive to salt, which can cause an increase in hypertension. Other factors, such as thyroid disease or family history, might increase the risk of heart problems [4]

As these diseases are fatal and can strike instantaneously if not treated on time, it is crucial to diagnose and monitor their occurrence frequently, especially when a person is above the threshold range of 60-65 years of age. To make this possible, there are various conventional techniques available in the market today that measure the heart activity of a person by an Electrocardiograph (ECG) thereby alerting them of any disability of the heart, if present. The different kinds of ECG measuring techniques range from highly detailed measurements in hospitals to portable and convenient ECG techniques to be used at home. Although conventional ECGs provide an extremely reliable assessment of heart health, they might not be the most accessible form of detecting CVDs. Regular, at-clinic ECG testing is inconvenient, costlier, and makes it impossible or difficult to detect cardiovascular diseases like arrhythmia [5], has frequent disconnections of cables [6], and is unavailable at all times to potential patients. Moreover, since early heart disease often doesn't have symptoms or in some cases, barely noticeable symptoms, at-home ECG kits provide access to a medical opportunity of 27/7 access to heart health assessment. This market, however, questions the controversy of reliability and trust due to multiple factors and not just accuracy. Current home-monitoring devices pose a problem of limited data [7], giving rise to a call for ambulatory tracking [8] which is at present not a feature of such devices being one of the factors leading most people using technological health monitoring to stop using it within a year [9]. Cardiovascular diseases being a leading cause of death have increased deaths globally by 60% from 12.1 million in 1990 to 20.5 million in 2021 [10]. Only 20% of those who die from heart diseases are under the age of 65, with the average age for a heart attack being 64.5 for men and 70.3 for women [11]. It is seen that the risk for heart attack increases significantly after the age of 45 in men and after the age of 50 in women [12], suggesting that heart diseases are majorly experienced by an old population, with an average of 65 years of age or above, which is 10% of the world's population [13]. A colossal market with technological setbacks sees major improvement through Machine learning models, Probability algorithms, and versatile designing of the device. We followed a straightforward 3 steps: The Hardware and Software assembly and installation, followed by The On-patient Test, and finally supplemented with a mental health evaluation. After recording the Cardiac signals, we professionally interpreted them with assistance from a certified practitioner. The interpretations were later used along with the survey scores to draw a reasonable conclusion.

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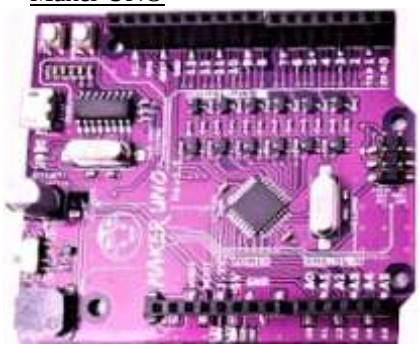
II. MATERIALS AND METHODS

2.1 The On-patient Testing:

To conduct our experiments and prove our hypothesis, we have made a portable prototype of an at-home ECG signal measuring device. Following is the description and working of the parts we have used in making the hardware of our prototype:

- Maker UNO



(Fig.2.1) Maker UNO

We have used the Maker Uno as a part of the hardware of our prototype, which is an Arduino compatible board designed to simplify building projects. It made our work easier as it makes the coding & electronics easy with 12 built-in LEDs, a built-in buzzer, and a button.

- BioAmp EXG Pill

(Fig 2.2) BioAmp EXG pill

To amplify the standards of medical technology specifically in detecting Cardiogram signals, our device functions using the BioAmp EXG Pill which is a convenient, versatile, and small-sized Analog Front End (AFE) board for BioPotential signal acquisition. In our prototype, we have used it with any 5v Micro Controller Unit (MCU) to capture organ or muscle signals. It can be set to plug into mobile and laptops via an intricate hardware connection, composed of the Arduino board, wires, and Gel electrodes in our prototype, It is therefore a useful device capable of recording publication-quality biopotential signals of ECG, without the inclusion of any dedicated hardware or software filters.

- BioAmp Cables

(Fig 2.3) BioAmp Cable

The BioAmp Cable is a 100 cm color-coded 3-pin electrode cable with JST PH 2.0mm connector on one side and snappable connectors on another side for easy connection between BioAmp Boards and the Gel electrodes. This cable is compatible with BioAmp EXG Pill and the Maker Uno board. We have used the third version of this BioAmp Cable (as shown in Figure 2.3).

- Gel Electrodes

(Fig 2.4) Gel Electrodes

Gel Electrodes are small pediatric medico gel electrodes (as shown in Figure 2.4). Our prototype, similar to the regular method, uses these to record biopotential signals from the human body by connecting these electrodes to the chest of the patient. It then works with the rest of the hardware to provide ECG signals by pairing them with the Bio Amp cables. Their small size and compatibility

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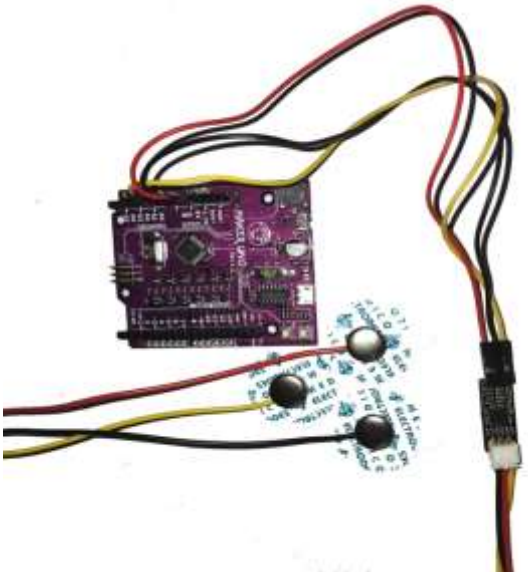
with Maker UNO and other microcontrollers make them a convenient choice for our device.



(Fig 2.5) The assembled hardware

After assembling the hardware as shown in (fig 2.5), we set up the software as follows:

- The Arduino Integrated Development Environment IDE was downloaded and installed followed by the Spike recorder application on our team members' respective PCs.
- The preliminary code was uploaded into the A IDE as shown in (figure 2.6)

(Fig 2.6) Arduino IDE Programming)

- The code implemented can be found here
- The spike recorder was then tuned to a suitable resolution (Low=4, High= 40) and frequency (50Hz/ 60Hz based on location)

Lastly, we integrated the hardware and the software of our prototype as shown in (Fig 2.7)

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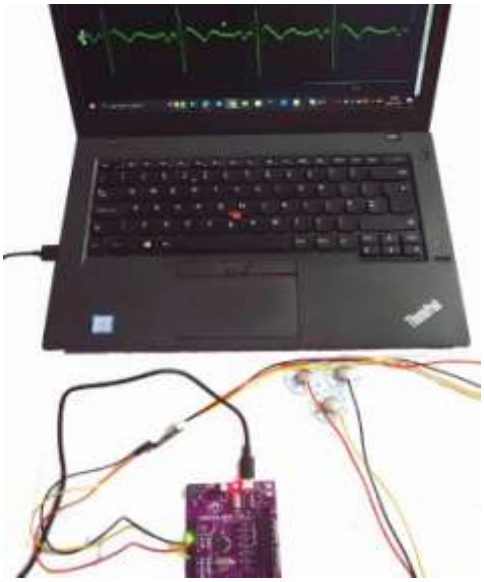

(Fig 2.7) Semi-Built, Assembled, and Connected (electrodes disconnected) Testing Device showing sample signals recorded at the time of testing of a patient through the Spike recorder Software installed on the windows system.

Upon successful installation and setup, we started the On-patient testing on patients with different backgrounds. Post-device setup we sterilized the testing areas of the skin using the skin-prep gel or plain alcohol cleansers.

We then started manually testing each subject using three gel electrodes that were connected to the subject's body. The positive (IN+), negative (IN-), and reference (REF) cables connected to respective electrodes were then fixed onto the gel electrodes. Considering the clavicle as a reference, we placed two of the electrodes right below the clavicle on the left and right halves of the chest. The third electrode was placed on the right in between/above the 11th and/or the 12th rib.

The readings were taken while following these precautions- charger disconnected from the PC, harsh background noise eliminated, and stayed precisely 5 meters away from air conditioners to avoid any interference with the ECG signal acquisition. Upon setup completion, the signals were plotted via the USB connection to the PC, and displayed on the Spike Recorder PC app.

The resolution and frequency were tuned before recording the signals following which they were sent for interpretation to a professional doctor, providing us with the cardiology reports of the subjects with varying ages, in a statement format.

2.2 Emotional and Physical Health: Verbal Examination

Our verbal examination consisted of warm-up questions, a survey to give an overall evaluation of loneliness, and an analysis of the subject's health records to analyze their history of hypertension, obesity, lifestyle, and even previous episodes of heart malfunctioning. Our subjects' responses to the survey will supplement the novel portion of our research and feed our dataset of their respective mental states and backgrounds. The initial approach to our survey is to make our subjects respond genuinely and unhesitatingly, taking into account that our targets include older and already possibly suffering from anxiety or palpitations. Building a conversation with our subjects using certain questions was not categorized as a survey or documented; it was rather an opening conversation about how they feel in terms of loneliness and stress and thereby did not include rankings, numerical responses, etcetera; The detailed answers of how they cope with health did not contribute directly, instead, it was an opening . These informal questions will give us, as experimenters, a broad category of patients to run the physical part of the experiment on—a lonely and fairly socially content population preferably above the age of 65.

Our questions will include, but are not limited to:

1. How does mental and physical health matter to you at this stage?
2. How lonely/stressful do you often find yourself?
3. Are you suffering from any Cardiovascular Disease?
4. How long have you been living alone?
5. Do you find yourself suffering from stress?
6. Are you a hypertension patient?
7. How often do you have panic/anxiety attacks or mental breakdowns (if any)?
8. Do you ever worry about your heart health?
9. How frequently do you talk to or visit your family/relatives/friends?
10. What mood do you find yourself in most of the time? Happy/Neutral/Unhappy?

Following session 1, we will be using the official UCLA Loneliness Scale as the survey for our subjects. This scale provides a near-accurate representation of loneliness ensuring no false testing or misinterpretation since loneliness often

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resides with other psychological issues. The questions are included below in Fig. 2.8

Statement	Never	Rarely	Sometimes	Often
1. I feel in tune with the people around me	1	2	3	4
2. I lack companionship	1	2	3	4
3. There is no one I can turn to	1	2	3	4
4. I do not feel alone	1	2	3	4
5. I feel part of a group of friends	1	2	3	4
6. I have a lot in common with the people around me	1	2	3	4
7. I am no longer close to anyone	1	2	3	4
8. My interests and ideas are not shared by those around me	1	2	3	4
9. I am an outgoing person	1	2	3	4
10. There are people I feel close to	1	2	3	4
11. I feel left out	1	2	3	4
12. My social relationships are superficial	1	2	3	4
13. No one really knows me well	1	2	3	4
14. I feel isolated from others	1	2	3	4
15. I can find companionship when I want it	1	2	3	4
16. There are people who really understand me	1	2	3	4
17. I am unhappy being so withdrawn	1	2	3	4
18. People are around me but not with me	1	2	3	4
19. There are people I can talk to	1	2	3	4
20. There are people I can turn to	1	2	3	4

(Fig. 2.8)The UCLA loneliness measurement questionnaire

III. EXPERIMENTAL TRIALS AND SURVEY RESULTS

3.1 Hypothesized Results

Our hypothesis revolves around an expected positive connection between loneliness and cardiovascular diseases especially among an old population. Loneliness causes stress which in turn causes hypertension and increases the risk for CVD. So, theoretically, loneliness should have a direct link to the increased risk for Cardiovascular disease and stroke. However, there is a chance that our hypothesis proves to be null. Therefore, the results of the experiments and the surveys we are conducting in order to prove our hypothesis may come out to be as the following:

Case 1: Proving the hypothesis

- Loneliness is positively linked to hypertension and other factors leading to the emergence of cardiovascular diseases among the old population.

Case 2: Presenting uncertainty

- Loneliness can be positively linked to hypertension and other factors affecting cardiovascular diseases, but it may not always be the case.

Case 3: Refuting the hypothesis

- Loneliness does not have any positive link to factors leading to cardiovascular diseases.

3.2 Empirical Results

3.2.1 Response, Aggregate Scores and Percentage Structure

The results from the UCLA loneliness estimation is shown in the table 1.0 which documents the percentage proportion of each response along with that of the people that are lonely

Questions asked for verbal examination	Out of 10 Subjects, % of Subjects that answered 1(Never) on a scale of 1-4	Out of 10 Subjects, % of Subjects that answered 2(Rarely) on a scale of 1-4	Out of 10 Subjects, % of Subjects that answered 3(Sometimes) on a scale of 1-4	Out of 10 Subjects, % of Subjects that answered 4(Often) on a scale of 1-4
I feel in tune with the people around me	30	0	40	30

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I lack companionship	10	30	30	30
There is no one I can turn to	30	20	10	40
I do not feel alone	20	40	40	0
I feel part of a group of friends	30	30	10	30
I have a lot in common with the people around me	30	0	40	30
I am no longer close to anyone	50	10	20	20
My interests and ideas are not shared by those around me	20	20	20	40
I am an outgoing person	30	20	10	40
There are people I feel close to	10	30	0	60
I feel left out	40	20	20	20
My social relationships arc superficial	0	50	20	30
No one really knows me well	30	20	20	30
I feel isolated from others	20	20	30	30
I can find companionship when I want it	30	10	40	20
There are people who really understand me	10	0	50	40
I am unhappy being so withdrawn	20	40	10	30
People are around me but not with me	40	30	10	20

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There are people I can talk to	30	0	20	50
There are people I can turn to	40	0	20	40

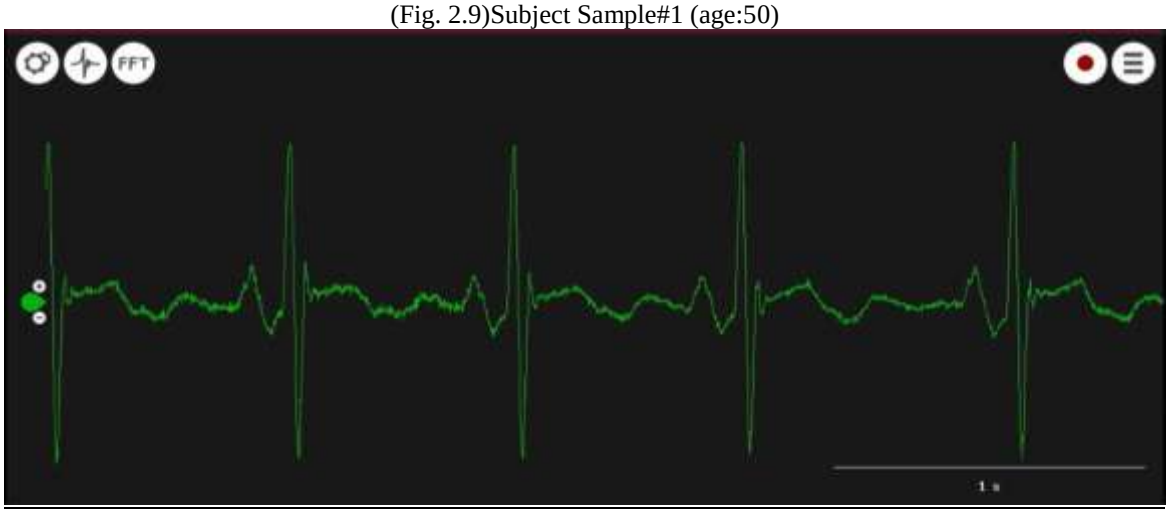
(Table. 1.0)

A. Percentage of subjects indicating low to moderate loneliness (Score of 20-40): 0%
B. Percentage of subjects indicating moderate to high loneliness (Score of 40-60):100%
C. Percentage of subjects indicating high levels of loneliness (Score of above 60):0%

3.2.2 Graph Samples and Interpretation

We performed experimental testing by checking the ECGs of our subjects with the prototype. It gave us a clear idea about their heart health and the risks they have of developing Cardiovascular diseases and the factors affecting them. We measured the ECGs of people of different ages and some of those readings are listed below:

(Fig. 2.9)Subject Sample#1 (age:50)



(Fig. 2.10)Subject Sample#2 (age:46)

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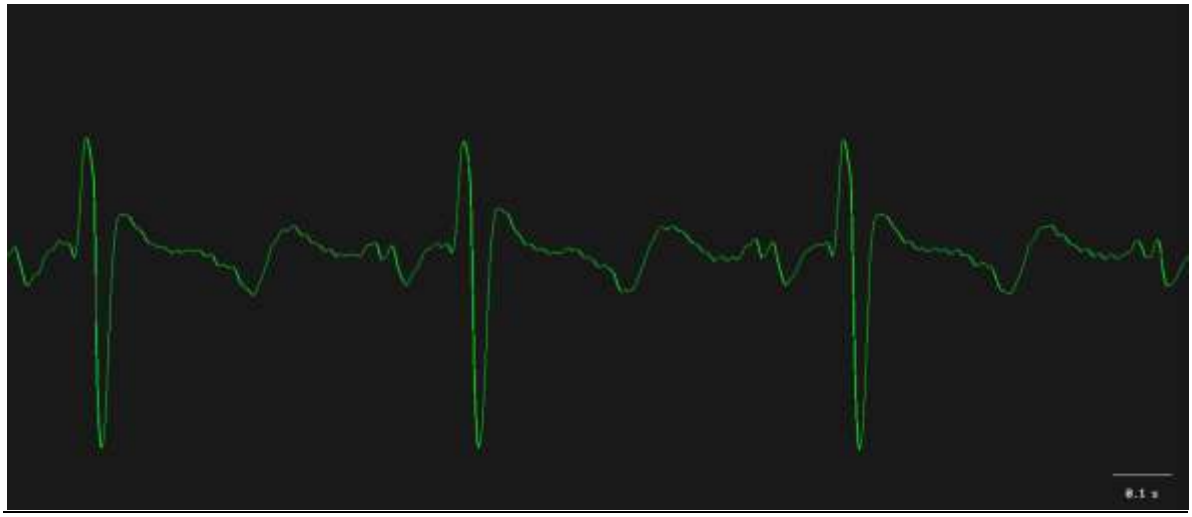
(Fig. 2.11)Subject Sample#3 (age 23):



(Fig. 2.12)Subject Sample #4 (age 57):

(Fig. 2.13)Subject Sample #5(age 67):

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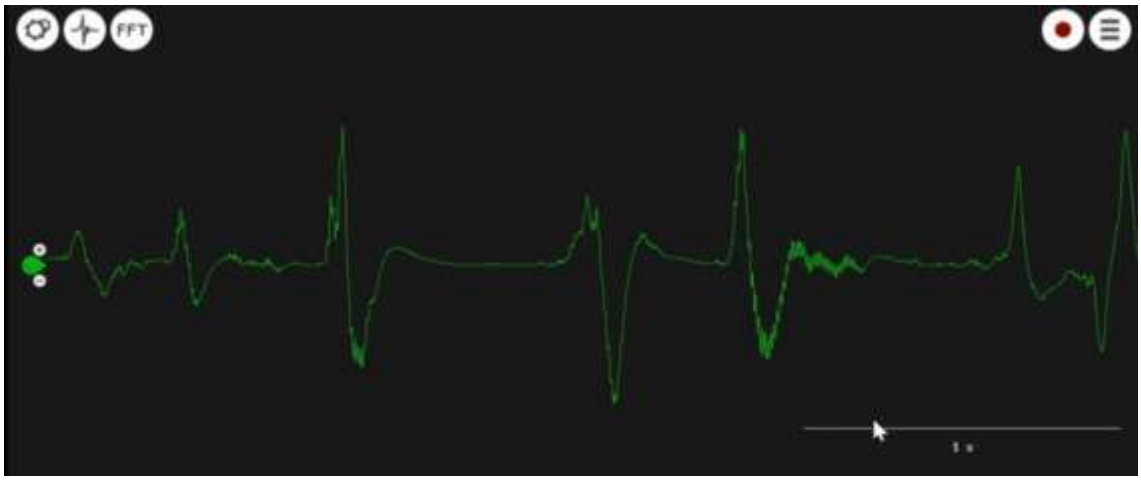
(Fig. 2.14)Subject Sample#6 (age 68):



(Fig. 2.15)Subject Sample#7 (age 79):

(Fig. 2.16)Subject Sample#8 (age 71):

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IV. DISCUSSION

4.1 Combined inference: Intersecting Mental Health and CVD

Based on the above dataset, we obtained via our ECG testings and Verbal surveys, we reached the following conclusions:-

- 5 out of 6 people who have been identified as highly lonely have also been detected as Cardiovascular disease risk patients.
- Out of all the subjects included in our tests and experiments, approximately 70% revealed a direct link between loneliness and Heart malfunctioning.
- Testing on people with an age lower than our target audience i.e., age ≥ 65 years with a low to moderate degree of loneliness as a control group led to us to find only 16% of subjects from the control group showed Heart malfunctioning, suggesting the results we got are reliable.

Therefore we confirm our hypothesis stating the accuracy of our prototype given that loneliness is notably one of the major risk factors of CVDs or stroke in humans.

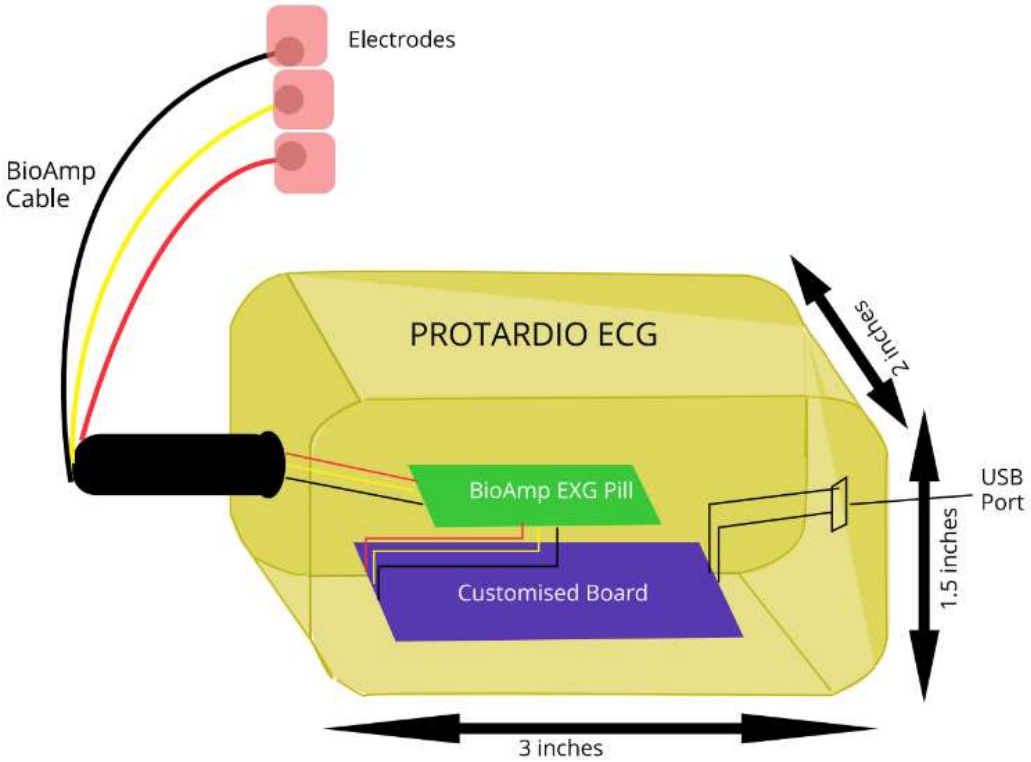
V. CONCLUSIONS & FUTURE OUTLOOK

5.1 Conclusion

After running real-time tests and in-person surveys on a broad group including lonely and non-lonely aged subjects with our semi-built prototype, we draw the inference that Loneliness, on the lines of Hypertension and Obesity, is a prominent risk factor impacting the probability of developing a stroke or a cardiac arrest, along with other risk factors - blood pressure, diet, and lifestyle. Moreover, aiming at the detection of heart irregularities with a 5 out of 6 accuracy, our research thus confirms our hypothesis to stand right. The current ECG tests we took to show that our prototype can measure ECG signals correctly and provide a clear picture of the Heart health. Our Verbal survey preceding these ECG tests confirms the positive linkage between Cardiovascular diseases and Loneliness.

5.2 Future Outlook

5.2.1 Model/Project Portability



(Fig. 2.17) Prototype Design

Primarily, we aim to increase the portability of our device to another extent since our current prototype can show ECG readings onto only Spike Recorder which is a PC app. We have

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started designing an application for mobile phones which can serve the same purpose. Then, we would include a customized board that is set to make the device extra portable with the EXG pill placed above the board. We will go for a custom PCB design, making our future prototype even more compact and portable, as even the Maker Uno we used had several unused ports which, during the testing, took a lot of space limiting the portability of our current prototype. We are aiming to make our future prototype of about 90 mm which is slightly more than the size of a human index finger (69 mm).

5.2.2 Model Accuracy

Developments using algorithms like Logistic Regression, SVCs, or Naive Bayes in the future for our prototype that could help to boost the accuracy of our device to nearly about 98-99%. This will be combined with a larger dataset of subject ECG samples that we will be taking in the near future, for improved accuracy.

5.2.3 Continuous Monitoring

Introduction to continuous or regular ECG monitoring of the subjects if they are suffering from any kind of heart disease, making them have a regular check on their heart health. The results obtained may be sent to their family doctor or a nearby doctor in real-time, where subjects generally get checked up.

5.2.4 Implementing ML Algorithms

Implementation of ML algorithms in our prototype will ensure more accurate predictions of the responsible risk factors causing a different ECG in the subjects. These algorithms work extremely fast and can easily predict the class of a test dataset. They can be used to solve multi-class prediction problems in our research for finding out the probabilities and help in making predictions as they are quite useful with them. These algorithms perform better than other models with less training data if the assumption of independence of features holds.

5.2.5 Generative Suggestion

With all the above improvements our prototype would give suggestions to the subjects on how they can reduce their chances of developing a stroke or a cardiac arrest depending on the affecting risk factors involved in each subject.

5.2.6 Automated Interpretation

Subjects with specific heart conditions or diseases can be notified via the app, we will be designing for the smartphones. The subjects may also be notified when they need to check their ECG, at what time, or in which case they must visit a nearby doctor.

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Footnotes

Author contributions

T.S.B. formulated the novelty; R.D., L.Z., T.S.B., B.M., executed a background check on the purpose, audience, and market opportunity; R.D. initiated verbal survey; T.S.B. undertook the application for our prototype's outreach; L.Z. explained the interpretation of standard ECG graphs; R.D., L.Z., T.S.B., B.M. setup and installed the prototype's hardware and software respectively; R.D., T.S.B. ran over 10 functional experimental tests on the subjects while L.Z., T.S.B., and R.D. attempted over 16 initial trials prior to the successful experimental outcomes; R.D., T.S.B., L.Z., conducted the in-person survey; L.Z. analyzed the surveys and testings under the assistance of an experienced doctor; L.Z. formulated the conclusion; R.D., L.Z., T.S.B., B.M. scripted and drafted the final research paper. All the authors have granted approval to the final version of the report.

Competing financial interests

The authors declare no competing financial interests.

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