Master thesis

Unobtrusive long-term monitoring for Atrial Fibrillation

Cardiolab

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CONTENT

In Part one, the subject matter is explored; in broad terms, it addresses the questions what is the disease, what is the technology and what are the users. This exploration forms foundation on which this master thesis was built.

In part two, the synthesis connects the key elements from the previous Part, which results in a design direction and statement as well as a set of requirements. In turn, this leads to the creation of the concept.

In part three, the idea becomes real and tangible with a prototype. This prototype is then tested and evaluated.

PART I - ANALYSE

PART II - CONCEPTUALIZATION

PART III - EMBODIMENT

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My housemates, thank you all for coping with me in throughout my graduation!

EXECUTIVE SUMMARY

This master thesis project explores the use of Photoplethysmogram[PPG] technology to detect of Atrial Fibrillation[AF]. This project proposes a product-service service system for the detection and diagnosis of AF in the current healthcare system in The Netherlands. This thesis is based on interviews with cardiologists, general practitioners and literature research.

One in four middle-aged adults in Europe and the US will develop Atrial Fibrillation (Kirchhof et al., 2016). Furthermore, AF is associated with a five-fold risk factor of stroke, while other cardiovascular deaths, such as sudden death and heart failure, are common in AF patients. (Kotecha et al., 2014). AF is a progressive disease, it starts with short episodes that end by themselves, paroxysmal AF, then episodes that have to be stopped in a hospital, persistent AF, and eventually permanent AF. Diagnosing AF in the first stage is difficult, the episodes are short and random, while current monitoring devices only cover up to 48 hours.

Thus, the problem is that current diagnostic tools have too short a monitoring period to diagnose paroxysmal AF effectively. The proposal by Philips was to monitor over longer periods, using Philips' HealthWatch. However, the PPG technology, integrated in the current generation HealthWatch, is too sensitive to movements on the wrist position. This could still result in an inaccurate diagnosis.

PPG is a sensor technology that uses a LED to look at the reflections of the blood volume in the skin. Blood volume changes within every heartbeat in a predictable manner. From these changes, it is possible to extract information such as the heart rate. Using an algorithm, it is possible to diagnose AF from this kind of information. However, PPG is also very sensitive to the movement between the skin and the sensor.

After an initial exploration of the subject the design proposal was formulated as follows: "To provide a low threshold tool to support the initial diagnosis of (paroxysmal) atrial fibrillation for the General Practitioner while collecting useful data for the further treatment and providing support for the patient."

This proposal led to the creation of Afi, which is a small diagnostic tool based on PPG, that can be deployed by the General Practitioner for unobstructed longer-term monitoring. The Afi is usually placed on the upper arm of the user.

Afi was evaluated with some users and healthcare professionals [HCP], namely a GP and a leading cardiologist. The evaluation with the HCP demonstrated that Afi has excellent potential as a new way of diagnosing AF.

CARDIOLAB AND MY GRADUATION

Cardiolab is a new initiative for a Delft design studio, set up by Delft University of Technology , together with Philips design and the Dutch Heart Association. The aim is to gain knowledge and develop new solutions in the cardiovascular field by sharing and working across a wide range of knowledge areas.

My graduation is the first project of the Cardiolab, this gave the project an extra challendge, which included alot of learning expierences for me.

The start of my graduation is an assignment from Philips to develop a support structure around the Philips HealthWatch to detected Atrial Fibrillation[AF].

GENERAL INTRODUCTION TO THIS REPORT

This thesis focusses on the detection of Atrial Fibrillation. Philips asked me to propose a support system for this, using photoplethysmogram[PPG] which is the sensor in the Philips HealthWatch. To build a support system around the Philips HealthWatch requires an understanding of three main elements: Atrial fibrillation itself, the medical system around it and the technology of in the Philips HealthWatch. This understanding was developed through interviews with cardiologists, researchers from Philips and some General Practitioners. In addition, literature research was done to create a deeper insight into all the aspects. In Figure 1 these are shown as the first two steps. Then I completed the analysis by combining these insights, evaluating the different options and choosing a direction. In Figure 1 this is the third step. From this point the concept development phase starts, by ideating ideas, prototyping these and, eventually, testing them. These are the final three steps.

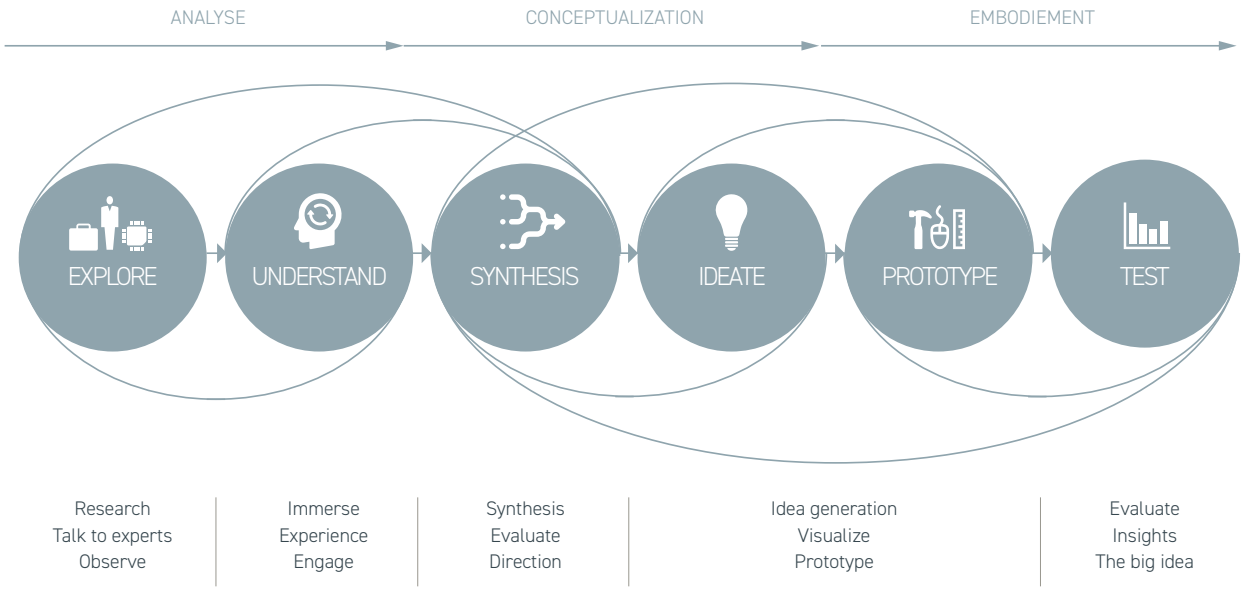


Figure 1. **Process of my graduation**

PART I - ANALYSE

Atrial Fibrillation [AF] is a quivering of the atria resulting in an irregular heartbeat (arrhythmia) that can lead to blood clots, strokes, heart failure(Sharma, 2011) and other heart-related complications. Studies show that 20–30% of patients that suffer from a stroke have AF, which is diagnosed around the time of the initial stroke event (Kishore et al., 2014; Grond et al., 2013). In 2010, the estimated number of men and women with AF worldwide was 20.9 million and 12.6 million respectively, with a higher prevalence in more developed countries (Chugh et al., 2013). The Hartstichting [The Dutch Heart foundation] believes that there are around 1.75 % of the population in the Netherlands that suffer from AF. It is suspected that around a third have remained undiagnosed till now. "By 2030, 14 to 17 million AF patients are anticipated in the European Union, with 120.000 to 215.000 newly diagnosed patients per year" (Kirchhof et al., 2016). The current diagnostic tools are accurate, however, they are invasive, obtrusive and cannot measure for longer periods of time, which is necessary for reliable diagnosis. To overcome this Philips has started to look into the possibility to detect AF with the aid of Photoplethysmogram [PPG] technology, which is essentially a light-based heart rhythm sensor. This sensor is already widely used in smart- and sports watches. The technology has the potential to create an unobtrusive long-term monitoring device for AF, which will substantially reduce the burden AF places on the healthcare system by detecting it at an early stage.

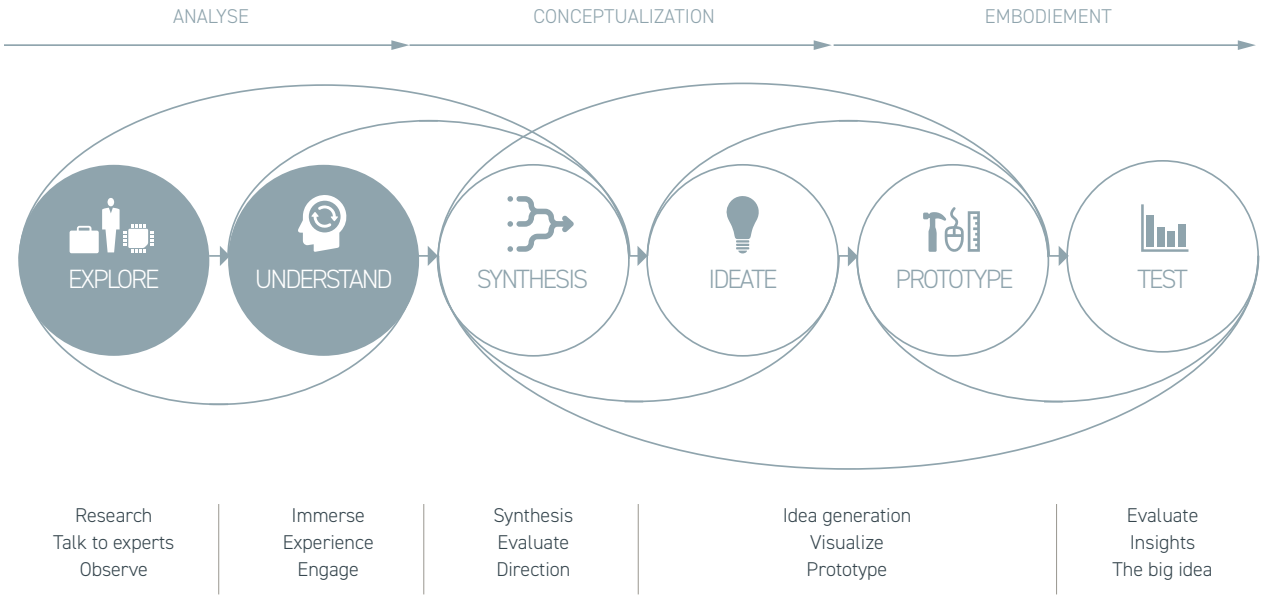


Figure 2. **Steps of the analysis part**

1. - ATRIAL FIBRILLATION

Atrial Fibrillation [AF] occurs when the atrial chambers of the heart start to quiver very fast, leading to an irregular heartbeat (arrhythmia). The quiver itself is not very dangerous. However, it can lead to blood clots, stroke, heart failure and other heart-related complications. (Afiponline, 2017), AF can be very unpleasant for the patient. AF can create palpitations, shortness of breath, fatigue and dizziness. However, a patient can also be completely asymptomatic. Signs of AF can vary widely and also be extremely vague. To design a tool to monitor AF, its characteristics should be well understood.

1.1 WHAT IS ATRIAL FIBRILLATION ?

1.1.2 Anatomy of the heart

To understand AF, a fundamental understanding is needed of the way a normal heart functions [Figure 3). The heart consists of two upper chambers called the atria, and two lower chambers called the ventricles. The atria pull the blood into the heart towards the ventricles, which push the blood through the body.

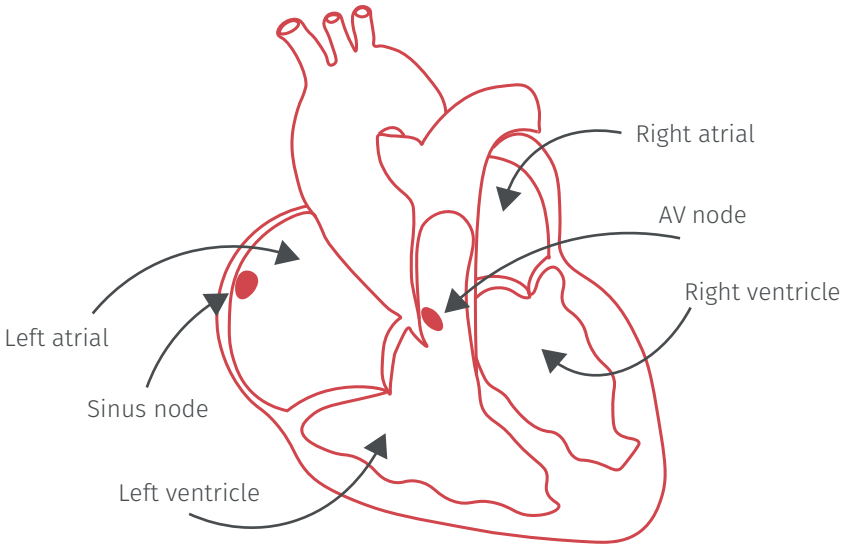


Figure 3. **Anatomy of the human heart**

1.1.3 Signals

The pumping muscles in the heart move by an electric signal, which starts at the sinus node [Figure 4]. This signal travels through the atria, resulting in its pumping movement. The signal then reaches the atrioventricular node [AV-node], which acts as a link from the atria to the ventricles, causing the pumping action of the ventricles. (Beckerman, 2017).

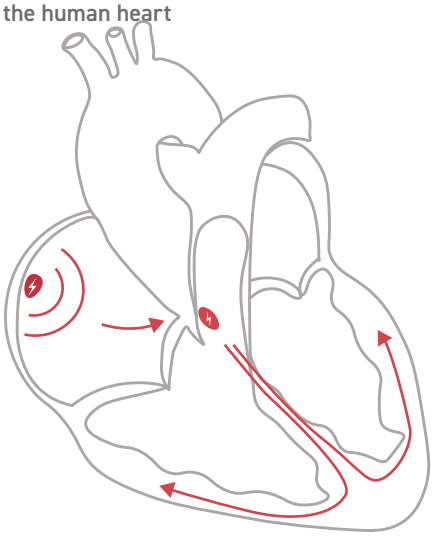


Figure 4. **The electric signals**

A good way to observe the action of the heart is by looking at an ECG recording. An ECG records the electrical activity of the heart muscles, which polarise and depolarise resulting in a heartbeat. The ECG is made by placing electrodes on the skin. The areas where you put these electrodes depend on the type of ECG. (Steinbaum, 2017)

1.1.4 QRS complex

During each heartbeat, a healthy heart has an orderly progression of depolarization that starts with pacemaker cells in the sinus node, spreads out through the atrium, passes through the AV-node down into the bundle of His and the Purkinje fibres, spreading down and to the left throughout the ventricles. This orderly pattern of depolarization gives rise to the characteristic ECG tracing. To the trained clinician, an ECG conveys a large amount of information about the structure of the heart and the function of its electrical conductive system (Walraven, 2011). This orderly pattern results in the QRS complex that can be (Figure 5 shows one QRS complex, Figure 6 shows an ecg) The QRS complex derives its name from the names of the peaks in the pattern.

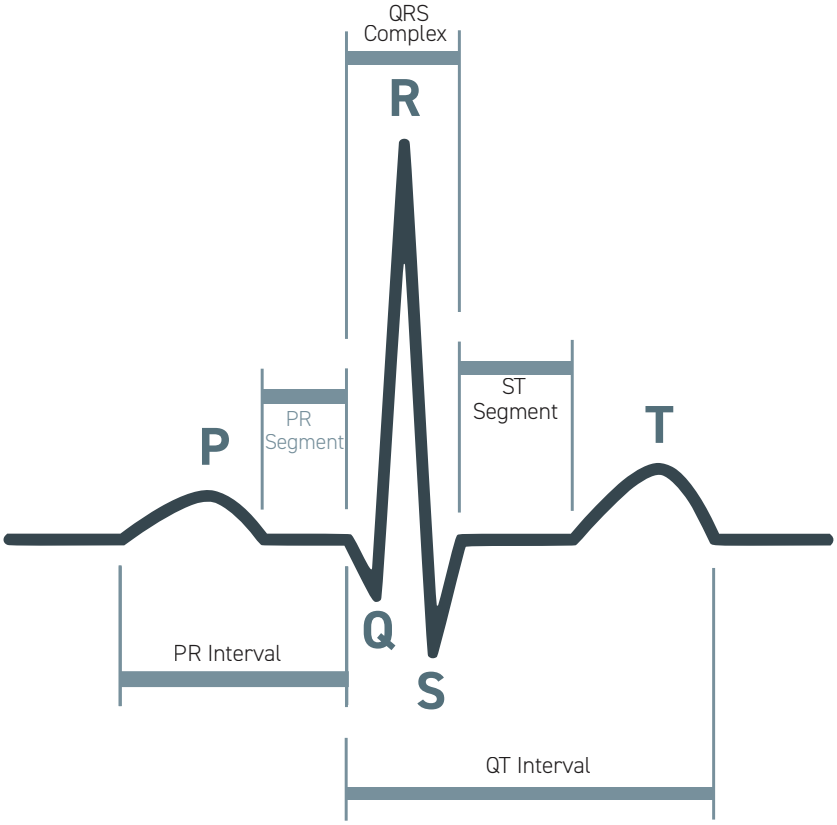


Figure 5. **QRS complex**

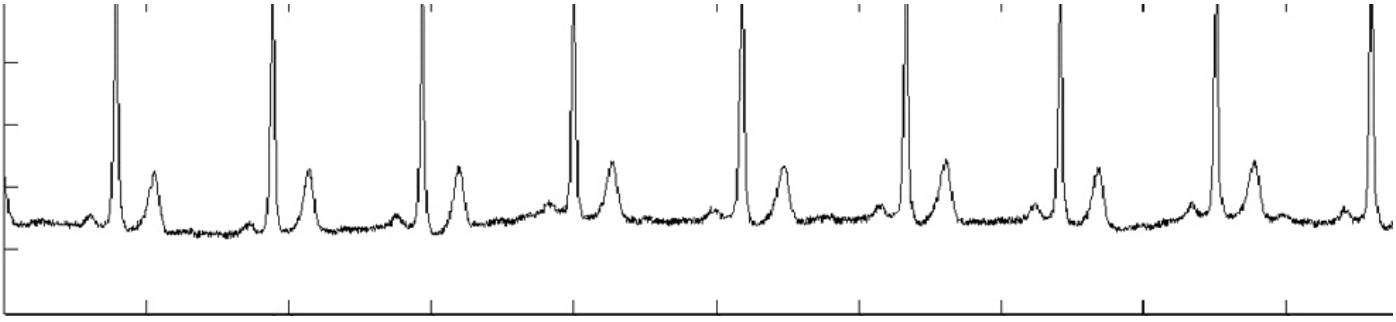


Figure 6. **Normal ECG**

1.1.5 Atrium Fibrillation

When AF occurs, there are random electric signals travelling through the atria that are causing a pace of 400 to 600 beats per minute in the atrial chamber. (Waktare, 2002), The result is an effective standstill of the pumping action in the atria chambers. ("dr. J. de Groot, personal communication,", 2017). When one of these random signals reaches the AV-node [Figure 7], and the tissue is sensitive to the signal (during the refractory period, which is the time the AV-node can 'accept' such a signal) the signal is sent through the ventricle via the AV-node, producing a heartbeat. (Waktare, 2002)
The source of these 'random' signals

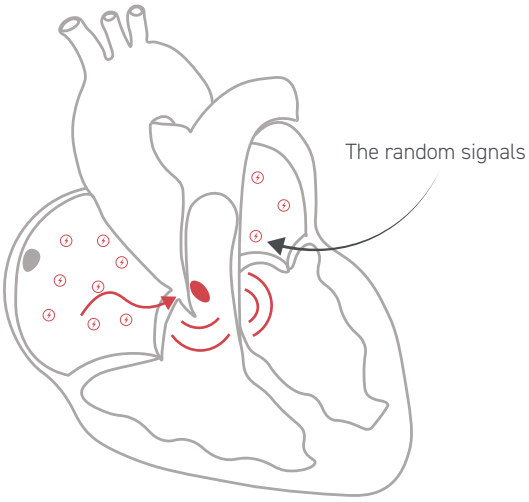


Figure 7. **Random signals**

"A healthy heart is like a nice red steak, however when you have AF it is like a steak with a lot of white tendons in it, these tendons are the scars in the heart and do not conduct the signal right from the sinus to the AV node ." - Prof. I.C. Van gelder

is an extra pulse in the sinus node. As such, the extra pulse is very normal to humans. However, when AF occurs, the signals re-enter the atrial chamber as a result of scar tissue in the heart and then continues to go around in the heart (Figure 8). This is what causes the quivering response of the atria. ("prof. dr. I.C. van Gelder", 2017;). Looking at Figure 8, the dots represent the scar tissue and the arrow the signal from the sinus node.

The quivering of the heart is a beating action of the atria at a rate of 300 to 600 contractions per minute. This effectively brings the blood in the Atria to a standstill ("prof. dr. I.C. van Gelder, personal communication", 2017). The AV-node will not beat at this speed due to the refractory, which is the time the av-node is available for the signal from the atria, time it needs. (Waktare, 2002). However, the flow of blood to the ventricles is limited. Therefore, the blood flow in the patient is suboptimal and this can lead to shortness of breath and make the patient feel very tired.

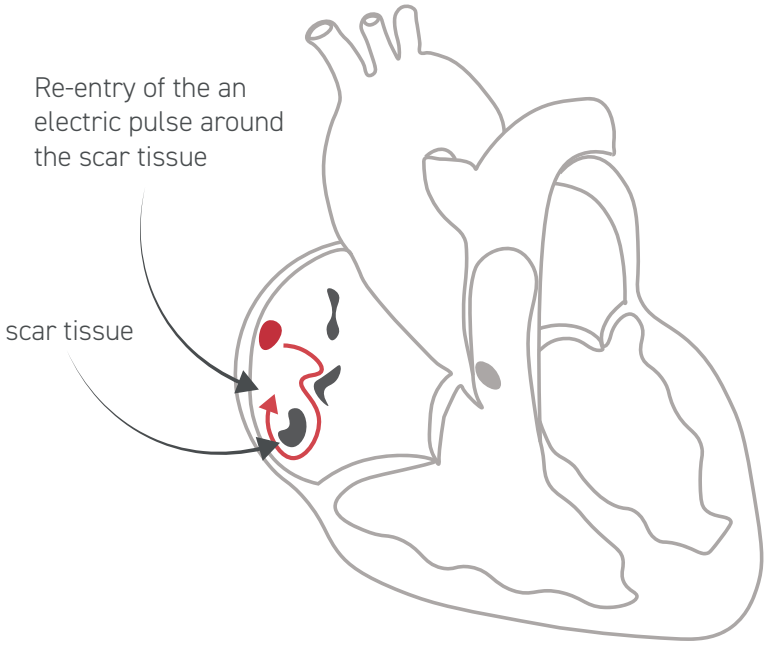


Figure 8. **Scar-tissue**

1.1.6 Atrial fibrillations on ECG

When a cardiologist is looking for AF, he or she is checking the P-top that can be found near the QRS complex. The P-top correlates to the signal from the sinus node in the atrial chamber. In a healthy heart, the P-top is visible just before the QRS-complex. However, when the atrium is a state of fibrillation, the P-top disappears.[Figure 9] This is because the random signals take over from the signal from the sinus node. ("What does AF look like? - The University of Nottingham", 2017)

"The pace of the atria so fast that is it's almost like the heart shakes itself apart" ("dr. Joris de Groot", 2017)

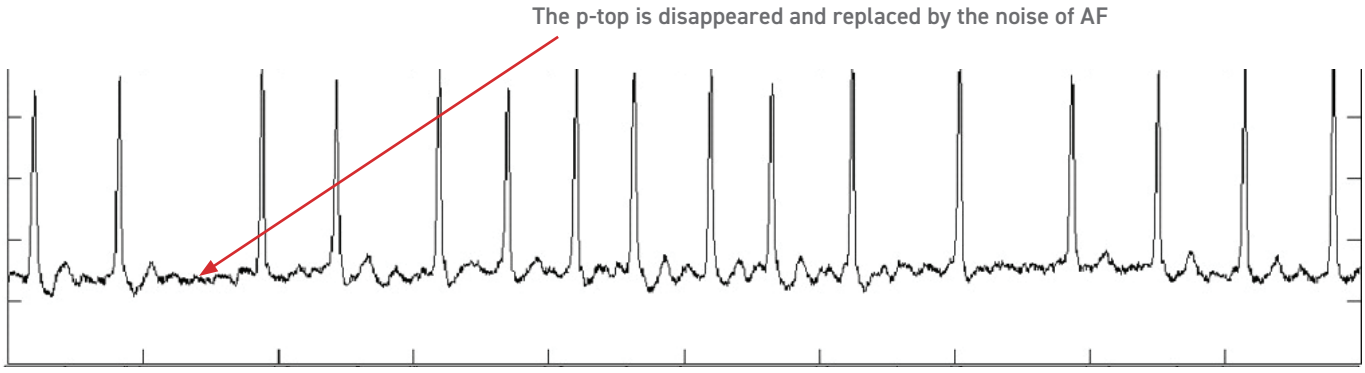


Figure 9. ECG with clear AF visible

1.2 HOW DOES AN ECG WORK?

The ECG is the most established way of detecting arrhythmias such as Atrial Fibrillation. The ECG is used as the reference ('golden standard'), because it measures the actual electric signal of the heart. However, these ECGs are often made by using a holter, which is very obtrusive.

An ECG records the electrical activity of the heart muscles, which polarise and depolarise resulting in a heartbeat. The ECG is made by placing electrodes on the skin. The areas where you put these electrodes depend on the type of ECG.

The 'golden' medical standard is the 12-lead ECG, which has 12 leads [Figure 10]. This gives the cardiologist the capability to monitor the heart from different angles and obtain a broad range of information. There are also simpler ECGs such as the one/two lead ECG, which is more comparable with a heart rate sports band. There is also is the holter[Figure 11], which mostly does not employ a full 12-lead ECG. However, it is medical grade and portable.

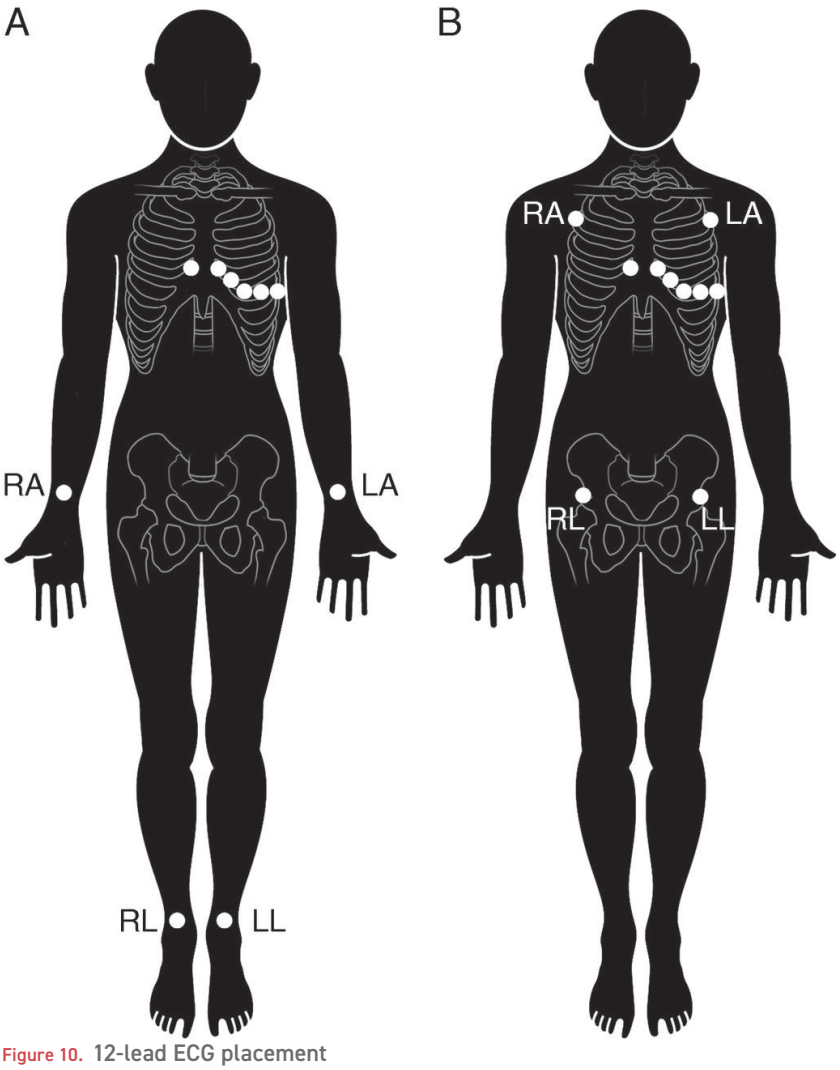


Figure 10. 12-lead ECG placement

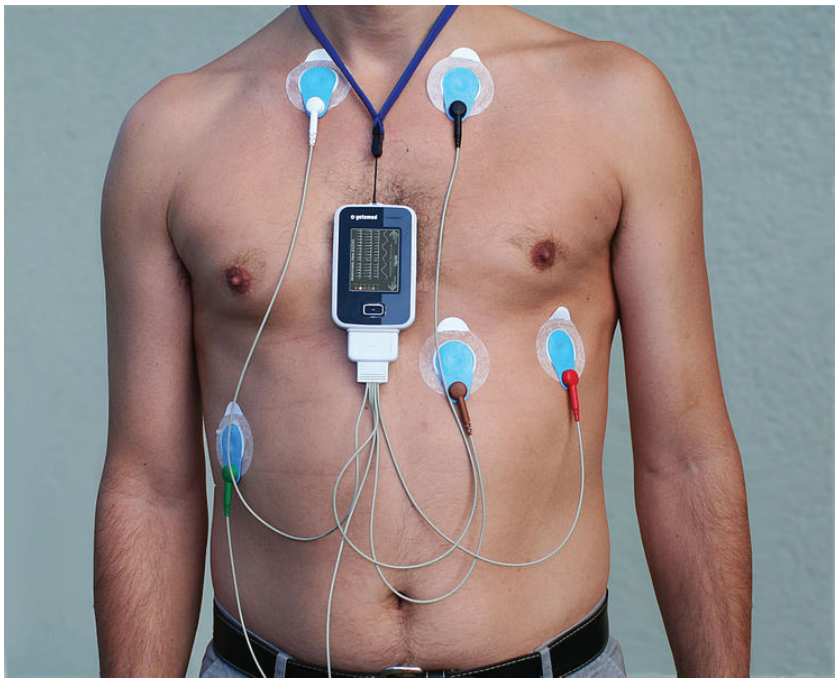


Figure 11. Holter

1.2.1 Building an ECG device

Using the ECG kit of DFrobot and an Arduino micro-controller (a prototype platform for electronics, which connects to the serial port on a computer), a simple ECG kit can be created (Figure 12) . The software is straightforward and is just a serial printout of the values received from the ECG kit. The Patches have to be placed on the body (Figure 12). Then the serial print shows the QRS complex. (Figure 14)

One of the biggest notes from this test was how incredibly sensitive ECG reads are to movement. One of the explanations is that it patches also the electrical activity of the muscles.

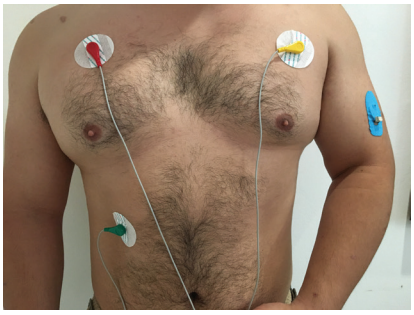


Figure 12. Simple ECG device

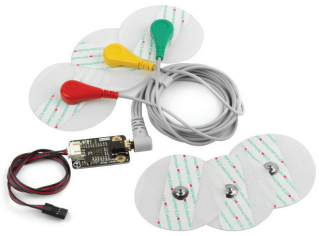


Figure 13. Simple ECG device

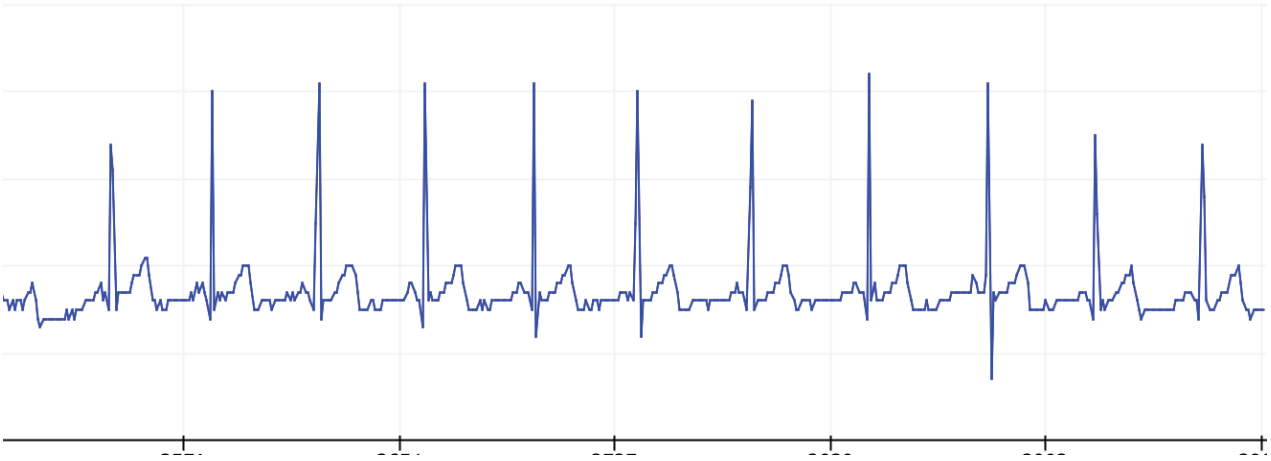


Figure 14. Upper line is AF on the ECG signal, lower line is the normal P-top

1.3 SYMPTOMES AND DEVELOPMENT OF ATRIAL FIBRILLATION

1.3.1 Symptoms

Symptoms can wildly vary between AF patients and may include ("Boezemfibrilleren", 2017)
- Heart palpitations (feeling that your heart is racing or fluttering)
- Awareness that the heart is beating.
- Chest pain, pressure, or discomfort.
- Abdominal pain.
- Shortness of breath.
- Lightheadedness.
- Fatigue or lack of energy.
- Exercise intolerance.

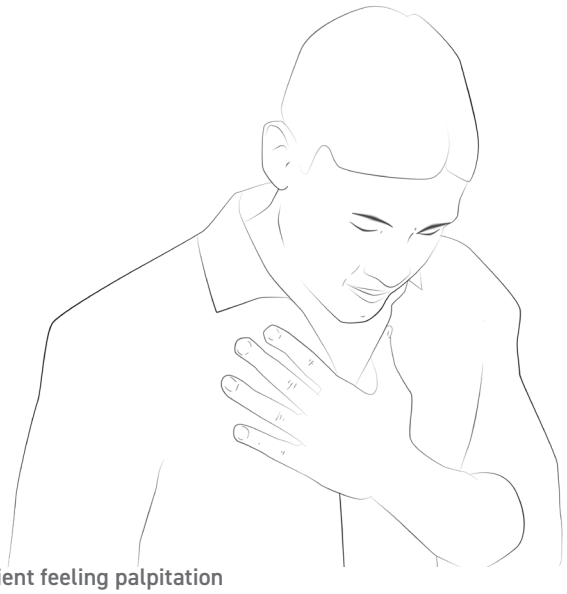


Figure 15. **Patient feeling palpitation**

1.3.2 The different stages of Atrial Fibrillation

AF is a progressive desease with three distinct stages of AF in the liturature: paroxysmal, persistent and permanent. Here these stages are briefly introduced and defined. The progression visible in Figure 16, the term burden is used to indicate the percentage of time a patient spends in an episode of AF. ("NHG-Standaard Atriumfibrilleren", 2009)

1) Paroxysmal AF is the stage of progression where the evens self-terminating; the duration of these episode can vary from less than a minute to seven days.

2) Persistent AF is the stage where an episode lasts more then seven days and often requires cardioversion.

Cardioversion is a medical intervention aimed at returning a heart to normal sinus rhythm. This can either be achieved through electrical shock or by administration of medicine.

3) The stage of permanent AF is reached when return to the regular sinus rhythm is impossible ("NHG-Standaard Atriumfibrilleren", 2009). Current data indicate that permanent AF occurs in approximately 50% of patients, and paroxysmal and persistent AF in 25% each (Zoni-Berisso, Lercari, Carazza & Domenicucci, 2014) However, AF always begins as paroxysmal AF after which it possibly progresses into the next stages.

1.3.3 Symptomatic vs asymptomatic

As stated before the symptoms of AF vary. Furthermore, the strain of the symptoms also differ per patient and even within patients. The strain is defined as the amount a patient suffers from symptoms. (NHG-Standaard Atriumfibrilleren, 2009) Some people have a higher strain than others, however evidence sugest that all patient have asymptomatic episodes. "among patients with stroke associated with AF, stroke was the first sign of AF in 24%. Paroxysmal atrial fibrillation (PAF), as opposed to permanent AF, is transient, infrequent, and often asymptomatic. In fact, up to 90% of PAF episodes may be asymptomatic." (Sinha, M.D., 2017) This while patients with permnament AF have a lower strain than patients with paroxysmal AF("prof. dr. I.C. van Gelder, personal communication", 2017).

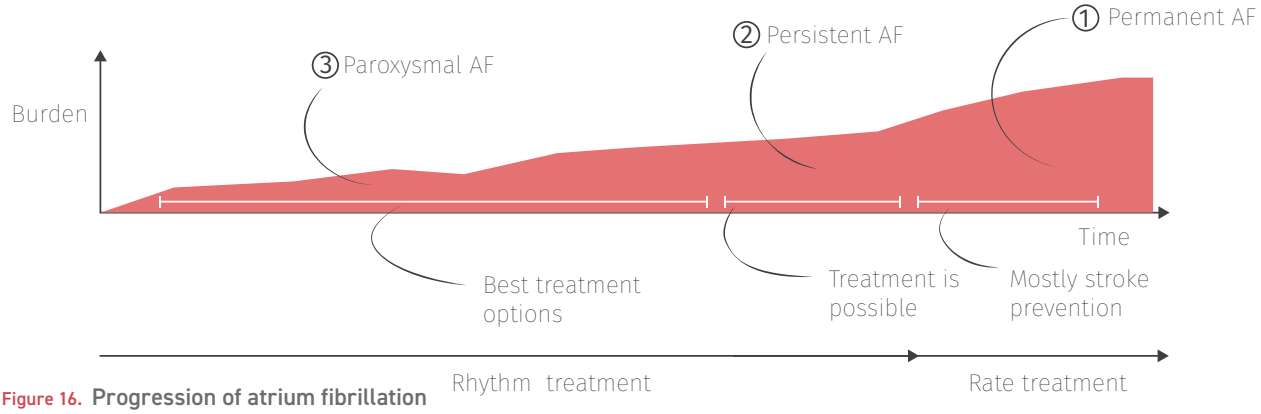


Figure 16. **Progression of atrium fibrillation**

In the early stages of AF progression, strain is often much higher than in later stages. This is in part due to the fact that patients in later stages often experience co-morbidities, e.g. other diseases that co-occur with AF.
The most significant co-morbidity to AF is hypertension, which is also one of the major causes of AF. "Hypertension is associated with a 1.8-fold increase in the risk of developing new-onset AF and a 1.5-fold increase in the risk of progression to permanent AF." (Ogunsua, Shaikh, Ahmed & McManus, 2015). Hypertension, commonly known as high blood pressure, occurs when the force of the blood against the arteries is too high, increasing the workload of the heart. Hypertension is often treated with beta-blockers, which inhibit the binding of adrenaline to hart muscles, thereby slowing the heartbeat and the power with which the heart pumps. ("Hypertension: Causes, symptoms, and treatments", 2017). However, it is important to realise that another effect of beta-blockers is that they can hide the symptoms, and thereby the severity of AF, by reducing the heart rate and the suffering of the patient. ("prof. dr. I.C. van Gelder, personal communication", 2017)
Furthermore, patients become accustomed to the feeling and strain that AF causes. In a way, patients get desensitised to the symptoms of AF and could increasingly develop into more asymptomatic patients. ("prof. dr. I.C. van Gelder, personal communication", 2017) In another point, this is visible that most of the AF patients have experienced symptoms, however when AF progresses they tend to have fewer symptoms. "In the Euro Heart Survey on Atrial Fibrillation, 69% of AF patients had experienced symptoms related to the arrhythmia at some point since diagnosis. The majority of patients (54%) were asymptomatic at the time of the survey, and the lowest symptom burden was reported in patients with permanent AF." (Rienstra et al., 2012)

In patients with persistent AF, particularly elderly patients, symptoms decrease or may even disappear with longer durations of the arrhythmia, and AF may become permanent (Rienstra, et al., 2012)

"It is true that paroxysmal atrial fibrillation causes much more strain than continuous atrial fibrillation " (Prof. IC van Gelder, 2017)

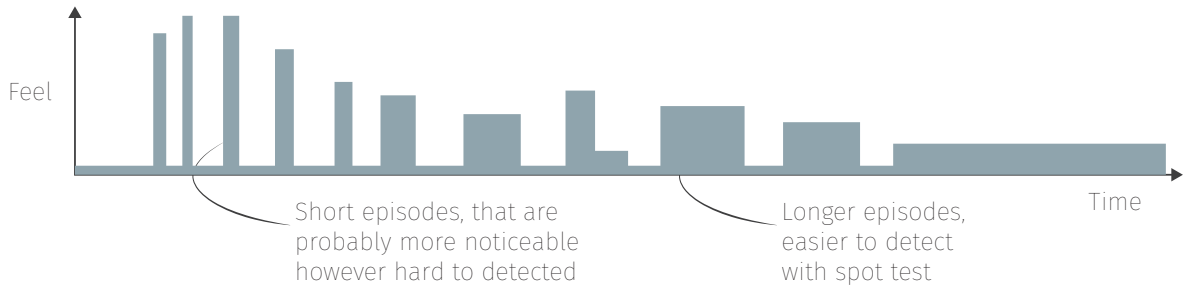


Figure 17. **When patient often feel the symptoms of AF the most.**

1.4 TRIANGLE OF COUMEL

Philippe Coumel was the founding father of the modern arrhythmology, one key concept he created was the triangle of Coumel. Coumels triangle [Figure 18] is seen as the conditions that have to co-exist before an episode of AF can start. The triangle of Coumel [Figure 18] consists of 3 factors, the substrate, trigger and modulator. To initiate and sustain an episode of AF, it is generally considered that all three elements must be present.

1.4.1 Substrate

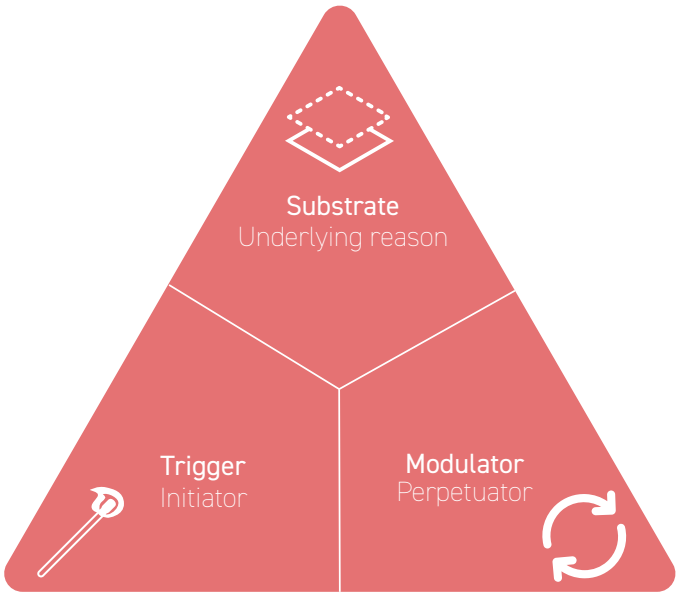
The substrate factor is the underlying cause of AF. This is, for example damage and scar tissue at the heart. It can be considered as the general health of the heart. If the heart is healthy the chance that an episode of AF will induce is small, and when a heart is sick, the chance of an event is higher. Factors such as blood pressure, heart failure(Sharma, 2011) and lifestyle influence this[Figure 19].

1.4.2 Modulator

The modulator is the factor that makes the episode of AF continue, in other words, the Perpetuator. These are for example the re-entry circuits that arise from the scar tissue in the heart. Re-entry circuits are scar-tissue in the heart were the electric signal can circle around. .

1.4.3 Trigger

The trigger is the signal that initiates an AF episode. This can be an extra heartbeat or a random signal from somewhere els in the heart. In other words, it is the "factor" that starts an episode.



Coumel's triangle

Figure 18. **The triangle of Coumel**

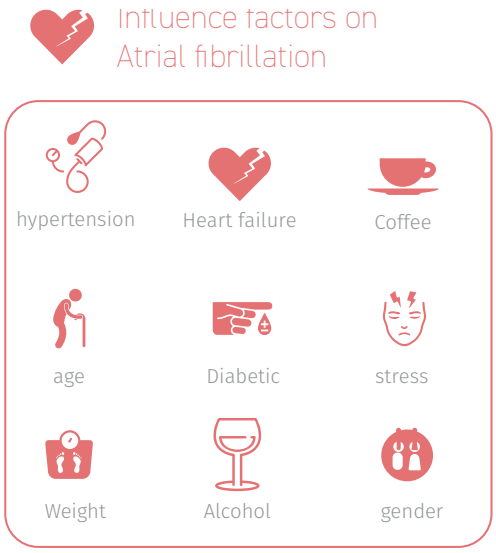


Figure 19. **influence factors**

1.4.4 Progression

The different elements in the triangle of Coumel [Figure 18 interact with one another. These feedback loops make chamber is guided differently. This change can bring on major complications for certain treatment options.

"By shortening the atrial refractory period, reducing conduction velocity, and provoking contractile and structural remodelling, AF may set the stage for self-perpetuation (i.e. 'AF begets AF')(Prof. I.C. Van Gelder)."

AF a progressive disease. [Figure 20] This is called re-modelling of the atria (de Groot et al., 2010). The disease starts with a single short episode, which creates a reinforcing loop that damages, for example, the substrate, leading to more episodes of AF. This causes the structure of the heart to change in such a way that the electrical current through the atrial Generally, since, the structure of the atria/substrate are least damaged when the disease has progressed least. "AF is a progressive disease, and persistent or permanent AF is associated with greater patient morbidity and mortality than paroxysmal AF. "
("dr. N. de Groot, personal communication,", 2017)

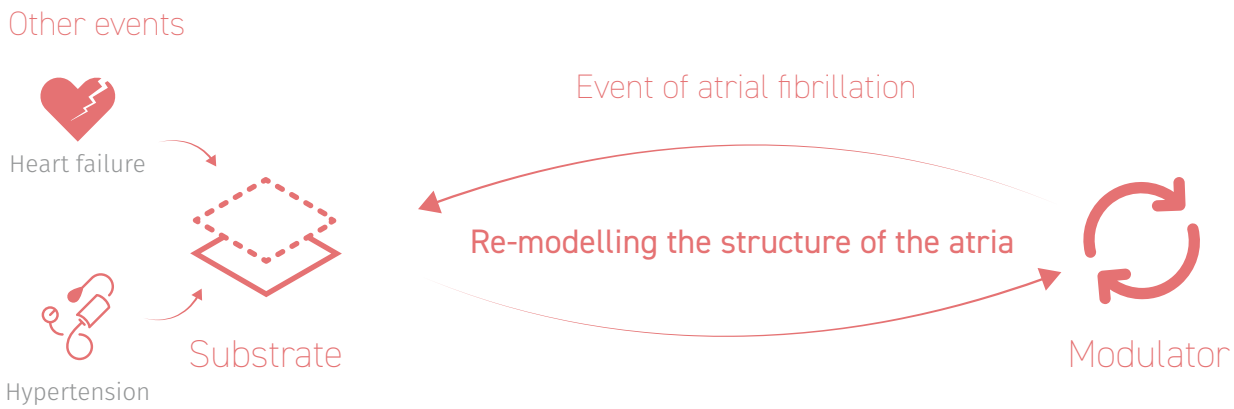


Figure 20. **Re-modeling the atria**

1.5 DISCOVERING AF

1.5.1 Holter test

A holter test is an portable ECG test in order to record the activity of the heart for a 'longer' periode of time. The holter test records the electric signal of the heartbeat from multiple points (leads) over a period of time. Typically, the test is performed over a time period of 24 to 48 hours. However, in the Erasmus Medical Centre (Rotterdam, the Netherlands), a 7-day holter test will be conducted if it appears that the AF has been successfully eliminated after an ablation (please refer to chapter 1.6.3 for more information on ablation therapy). The Holter test is highly accurate and not solely aimed at diagnosis of arrhythmias. The drawback, however, is that the test is highly obstructive for the patient: at least five cables are attached to the chest, whilst also having to carry a box with the recording devices for the entire duration of the test (Kirchhof et al., 2016).

Figure 22. **Holter test**

1.5.2 12-Lead ECG

The 12-lead ECG is the most accurate form of ECG and can only be conducted by specialists. This test is to check the whole function of the heart and is mainly done to find the underlying reasons for atrial fibrillation. The 12 indicates the number of leads. That is used in the test. Sometimes the test is performed during exercise on an exercise machine, which can induce arrythmias. (Kirchhof et al., 2016).

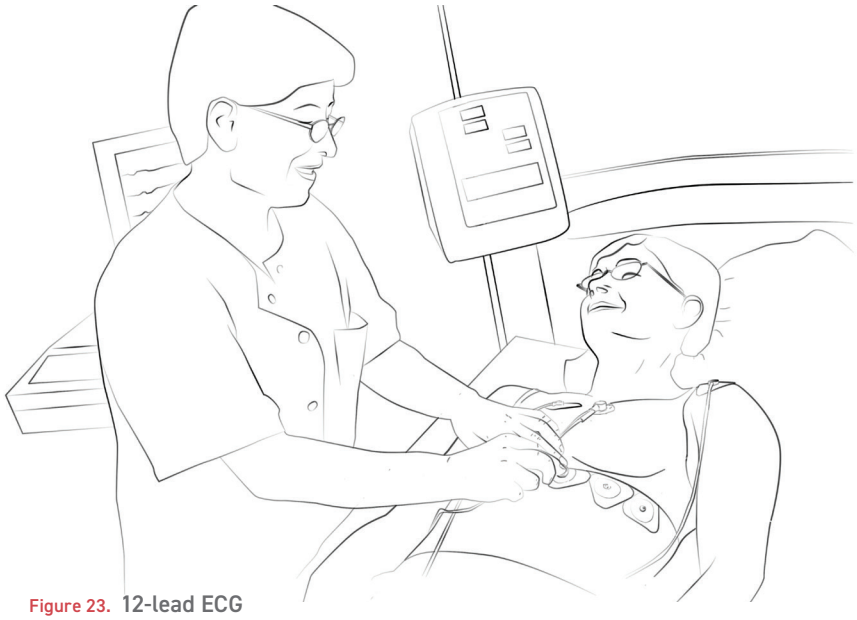


Figure 23. **12-lead ECG**

1.5.3 Undiscovered AF

The Dutch heart society estimates that, in the Netherlands, about 200.000 people are aware of their AF, whereas there are about 100.000 individuals who are unaware of their AF. This presents a problem: "ischemic stroke was the first clinical manifestation of atrial fibrillation in 37% of younger (<75 years) patients with no history of cardiovascular diseases. [...] atrial fibrillation is too often diagnosed only after an ischemic stroke has occurred, especially in healthy middle-aged individuals" (Jaakkola et al., 2016). The effects of a stroke and the risk will be discussed in 1.6.4.

Figure 24. checking on a patient

1.6 TREATING AF

1.6.1 Prescription drugs

There are three types of drugs used in the treatment of atrial fibrillation; Anticoagulant [OAC], rate control, and rhythm control drugs. OAC drugs are used to control the stroke risk, which will be discussed in 1.6.4. Rate and rhythm control drugs are used to control the heart rate so that it stays within acceptable parameters (Kirchhof et al., 2016)

1.6.2 Cardioversion

Cardioversion is performed in order to end an episode of AF and return the heart to a sinus rhythm. When an episode lasts under 48 hours, it can be performed immediately. If the episode lasts for a period over 48 hours, a multi-day treatment with anticoagulant is needed before starting cardioversion. There are two types of cardioversion; one uses an electric shock, the other uses medication. For patients with paroxysmal AF, a specific drug treatment is available, Namely 'the pill in the pocket'. This treatment enables a patient to 'self-medicate' (Kirchhof et al., 2016).

1.4.3 Ablation therapy

Ablation therapy is a 'keyhole' surgery where the electrophysiological cardiologist a catheter is inserted in the groin of the patient and guided to the atrial chambers. In the atrial chambers it is used to create small scars. These scars are have he aim of isolating the random electrical signals causing atrial fibrillation. However, success rates of this therapy is considered low at 50% to 70%.

The highest success rate is achieved in patients at the earlier stages of AF (Kirchhof et al., 2016). This is most likely due to the decoupling of electrical conductivity at the persistent stage of AF. This decoupling causes the small scars to no longer be effective at isolating the random signals (AFIPonline, 2017)

1

Figure 29. Patient visting a pharmacy

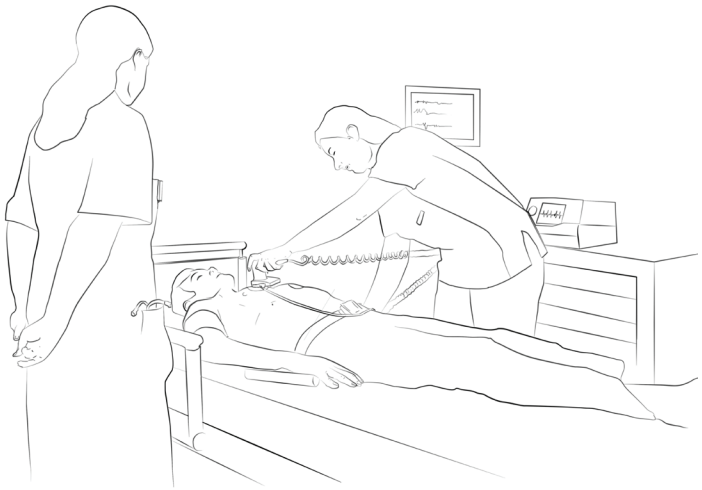


Figure 25. Electrical cardioversion

Figure 28. Ablation therapy

1.6.4 Stroke risk

With AF, there is an associated risk of thromboembolic complications (stroke). Some believe this might be due to the standstill of blood in the atria("dr. J. de Groot, personal communication,", 2017). However, this has not yet been proven and is still a topic of debate.

A stroke is one of the biggest acute dangers of AF, Even though AF is not directly harmful, a stroke is. A stroke occurs when a small blood clot blocks the blood supply to the brain. A stroke can cause vital damage and function loss consequences for the patient and might even be fatal. To prevent a stroke OAC is prescribed. OAC prevents the blood from clotting. Before prescribing an OAC, the risk of stroke should first be considered, prescription of OACs could lead to bleeding (Rubboli, 2011). The extend of the risk depends on the progression of the disease. This will be further discussed in chapter 2.5. In order to evaluate the risk of stroke, the CHA2DS2VASc-score[Figure 26] is determined (Lip, Nieuwlaat, Pisters, Lane & Crijns, 2010).

As can be seen in figure XX, If the sum of the factors are 0, no OAC is needed, when the sum is 1, OAC should be considered and higher than 1 OAC must be prescribed (Kirchhof et al., 2016).

Other co-morbidities of AF that influence the CHA2DS2VASc score include heart failure, diabetes, hypertension and other vascular diseases. All of these have a significant negative influence on the health of a subject. Furthermore, chances of reoccurrence are significant, thus when a patient has already been subjected to a stroke, their CHA2DSVASc score is doubled. Other factors that influence the score are age, which has a direct correlation to the risk of a stroke, and sex, with females tending to be at greater risk once initial risk factors are present.

It should also be noted that CHA2DS2-VASc scores predict long-term stroke outcomes in non-AF patients with acute ischemic stroke. These scores may provide an easy way to of stroke prognostic risk stratification among non-AF stroke patients. Making the score usefull even for patients not (yet) presenting with AF (Ntaios et al., 2013).

C	Heart failure	1
H	Hypertension	1
A_2	Age above 75	2
D	Diabetes mellitus	1
S_2	Stroke	2
V	Vascular disease	1
A	Age between 65 and 74	1
Sc	Female	1

Figure 26. **CHA2DS2VASc-score.**

Figure 27. **Having a stroke**

1.7 CONCLUSION

AF is a progressive disease and is difficult to detect in the early stages of the disease. The progressiveness of AF has a significant effect on the treatment options and the potential risks of the disease. Most notable that ablation therapy and cardioversions become almost non-effective at the last stage of the disease.

Furthermore, the current diagnostic procedures are not suitable for detecting AF in the first stages of the disease due to their relatively short measurement time.

This differentiation creates an inconvenient situation where on the one hand it is preferred to treat AF as early as possible, while on the other hand early detection is with the current detection methods is challenging.

This situation creates the question what happens in the present diagnostic procedure and is the proposed technology form Philips better suitable for AF detection?

Figure 30. **Lifestyle**

2. - PATIENT JOURNEY

Every patient has a story or a journey they go through. This journey is different for every disease. For some diseases, the journey is more predictable than for others. The journey of a patient with AF depends on multiple factors. These include: the profile of the patient, the stage to which the atrial fibrillation has progressed, the level of AF experience the general practitioner (GP) has and the symptoms the patient is experiencing. Due to the large number of possible combinations of these and other factors, it is not possible to construct a single patient journey for all patients.

2.1 DIFFERENT ACTORS

During the journey of diagnosis and treatment of Atrial fibrillation, a patient has a network of different actors surrounding him or her [Figure 31]. An actor is a party that is inlvolved with patient in anyway. Some of these actors are directly involved such as family or the GP, others like insurance are indirectly involved. In the journey map, we only consider the directly involved actors. Directly involved actors are defined as having a direct influence on the process.

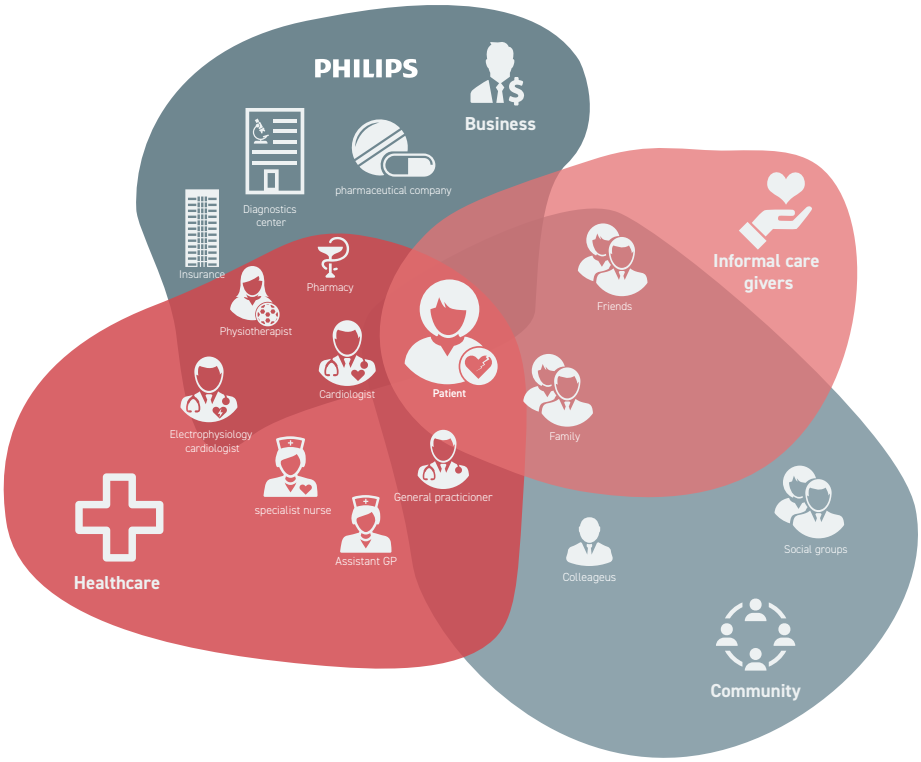


Figure 31. Map of the different actors around a patient

2.2 THE JOURNEY MAP

Since many different factors influence a patient's journey, not a single path can be predicted. This leads us to develop a map consisting of alternative scenarios, much like a flow diagram.[Figure 32]. In this map, the 'places' that a patient visit are leading rather than the time that the various steps or stages take. This map is based on the people and places with which the patient has the most interactions, as is further clarified in the stakeholder/actor map [Figure 31]. Although it is possible to add more places and/or people, such as the physiotherapist or the pharmacy, here a stakeholder map and patient journey limited to the major players and locations was considered.

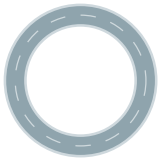
The journey starts at the home of the patients, and from there it continues to the different 'places' in the process. The roundabouts symbolise the possibility to 'stay' in a single location without a proper conclusion.

2.2.1 Methode

Prof I.C. Van Gelder, leading expert on AF in the Netherlands.

- Dr. J.R. de Groot, head of the Department of Clinical Electrophysiology in the Amsterdam Medical Center
- Dr. N.M.S. de Groot, Principle investigator of the lab, which focuses on AF in the Erasmus medical centre
- Prof. J.W. Deckers, cardiologists at the Erasmus medical centre
- Dr Hus, GP in Delft
- Dr. van t Lindenhout, GP in Delft
- Dr Galama, GP in Rotterdam

Furthermore, two guides have been considered; the guide for standard practice for GPs, the NHG-standard on Atrial fibrillation ("NHG-Standaard Atriumfibrilleren", 2009) and the guide for cardiologists, 2016 ESC Guidelines for the management of atrial fibrillation developed in collaboration with EACTS (Čihák, Haman & Táborský, 2016).



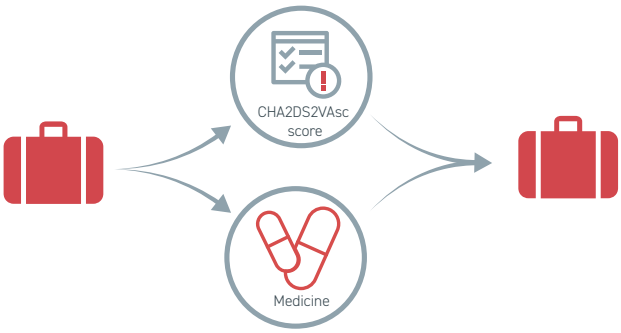
Roundabout IImplying a state of an unclear result for a patient

Road The width of a road implies the 'amount of traffic'

Person An actor in the map

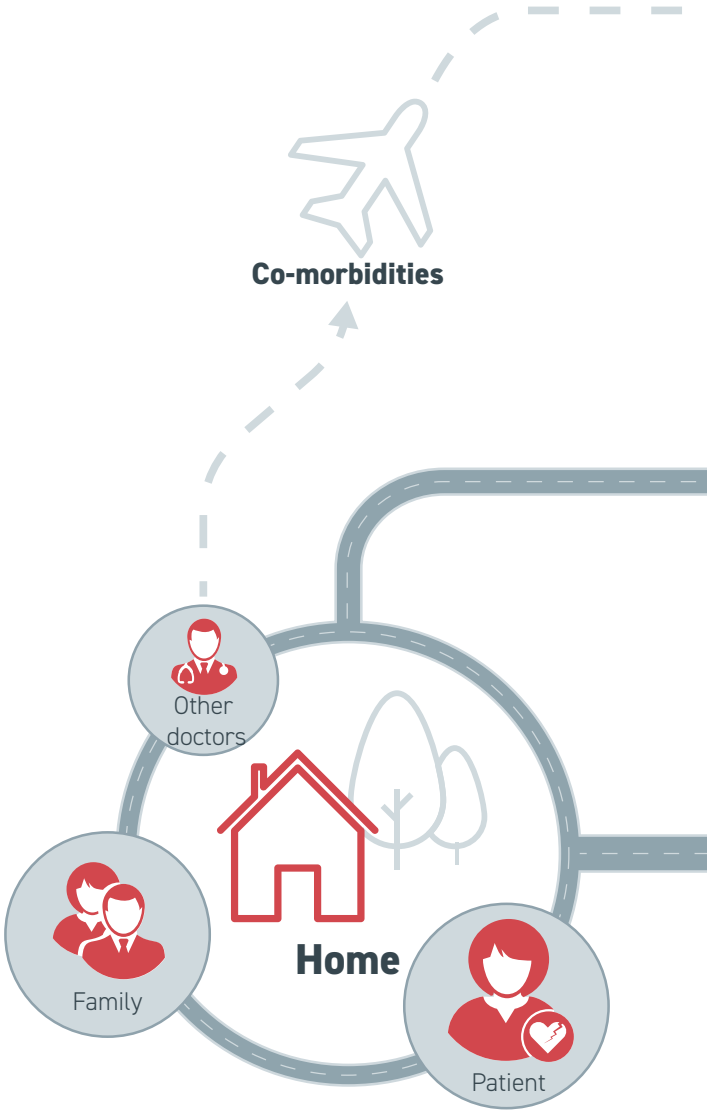
Action An Action an actor can use

Travel The car symbolises the travel direction the patients takes, the baggage implies the changing story



The story of a patient influences the actions of doctors

While the different actions influences the story of the patient



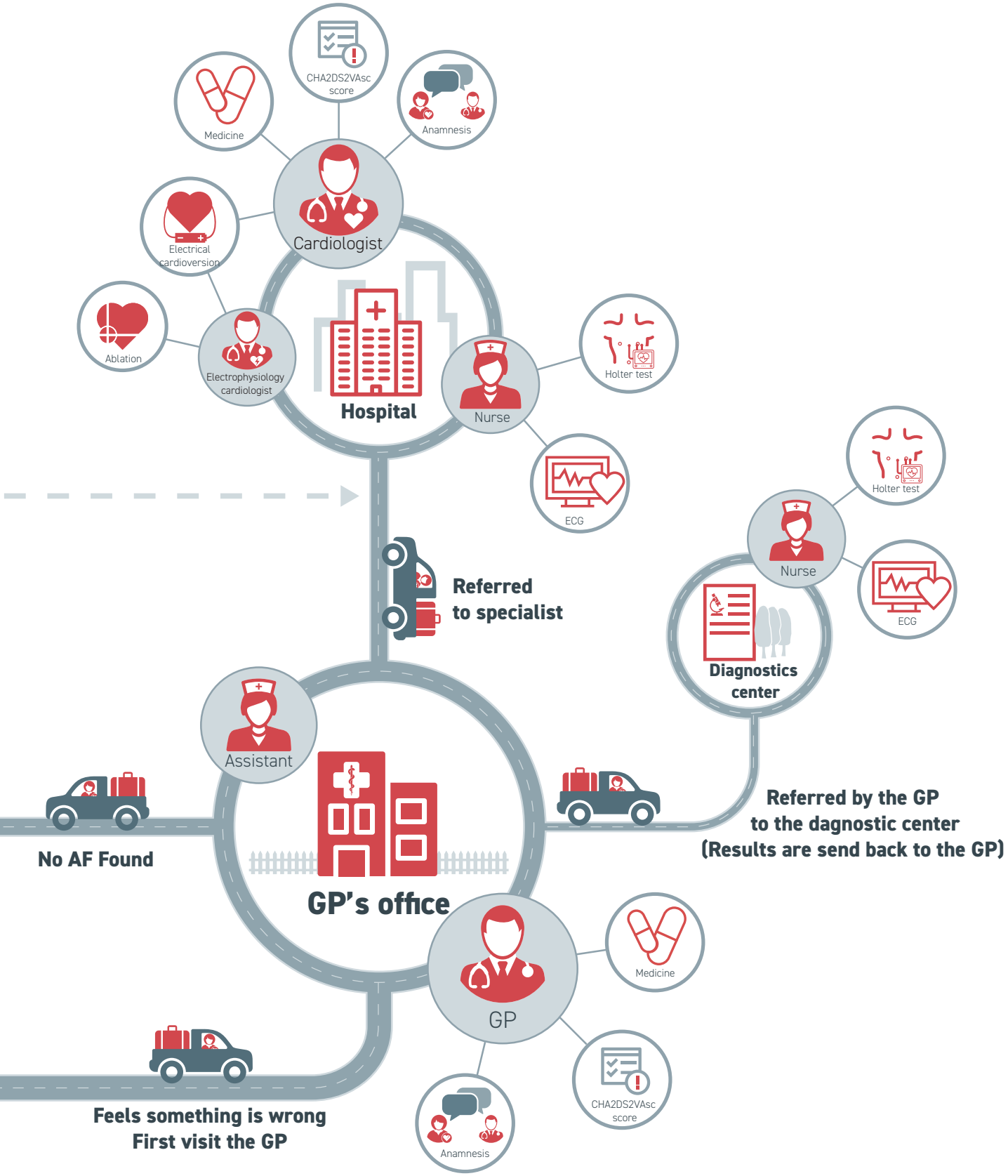


Figure 32. Patient journey map

2.3 PATIENTS ARE DIFFERENT

Defining the different types of patients for atrial fibrillation is outside the scope of this project. Nevertheless, it is important to recognize these different types of patients (Warth, 2017), who all have a different way of interacting (Woogara & Stephenson, 2017) with their GPs and Cardiologists.

The background story of a patient largely influences the type under which they can be categorised. This consists in large part of how much a patient is in touch with their own body, the way that they can tell their story convincing to
a GP, how soon they will consult a GP and more. Even though these factors have a large impact on the behavior and relation with the GP and therefore a patient's journey, they are very hard to quantify. It is however possible to identify two extremes in the types of patients; most patients will find themselves somewhere between these two types, rather then at the extremes.

The first type of these two extremes is the patient that does not consider the doctor as an absolute authority. This patient will conduct their own searches in order to collect data. This kind of patient often does not accept a diagnosis and continues to persist in their own believes. This type is often described as the stubborn pushers and know it all's (Van den Berg, 2014)

On the other side, there are patients that postion the doctor on a pedestal, and assume he or she is never wrong., This kind of patient passively undergoes the journey and are more likely just to try to avoid the situation they are in(Van de Berg, 2014).

Typing and the manner in which patients present themselves is of importance in the journey of the patient. For this project it is crucial to have a notice on this, however it has not the a big influencing factor for the final design. Therefore it is not ellaborated in this graduation project.

Figure 33. **Different kinds of patients.**

2.3.1 The patients personal space

In the journey described here, home symbolises the private life of the patient, surrounded by his or her family and to an extent friends and colleagues [Figure 35. These people are often the first to support a patient when they suffer from the initial symptoms of AF. Other doctors can also fall within this category as AF is sometimes only discovered when a patient is already under treatment for a different complaint, for example in the case of a hip replacement.

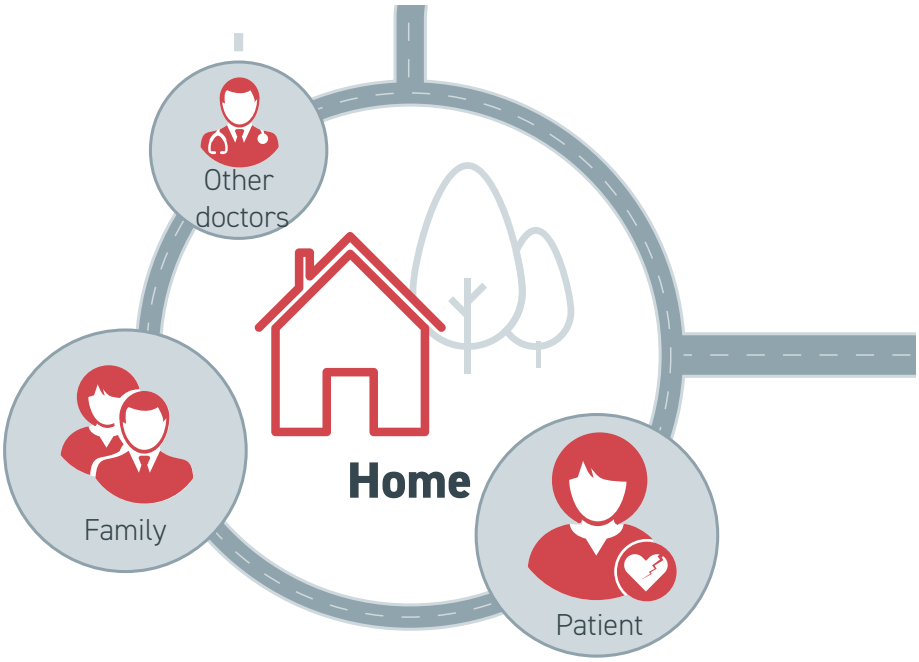
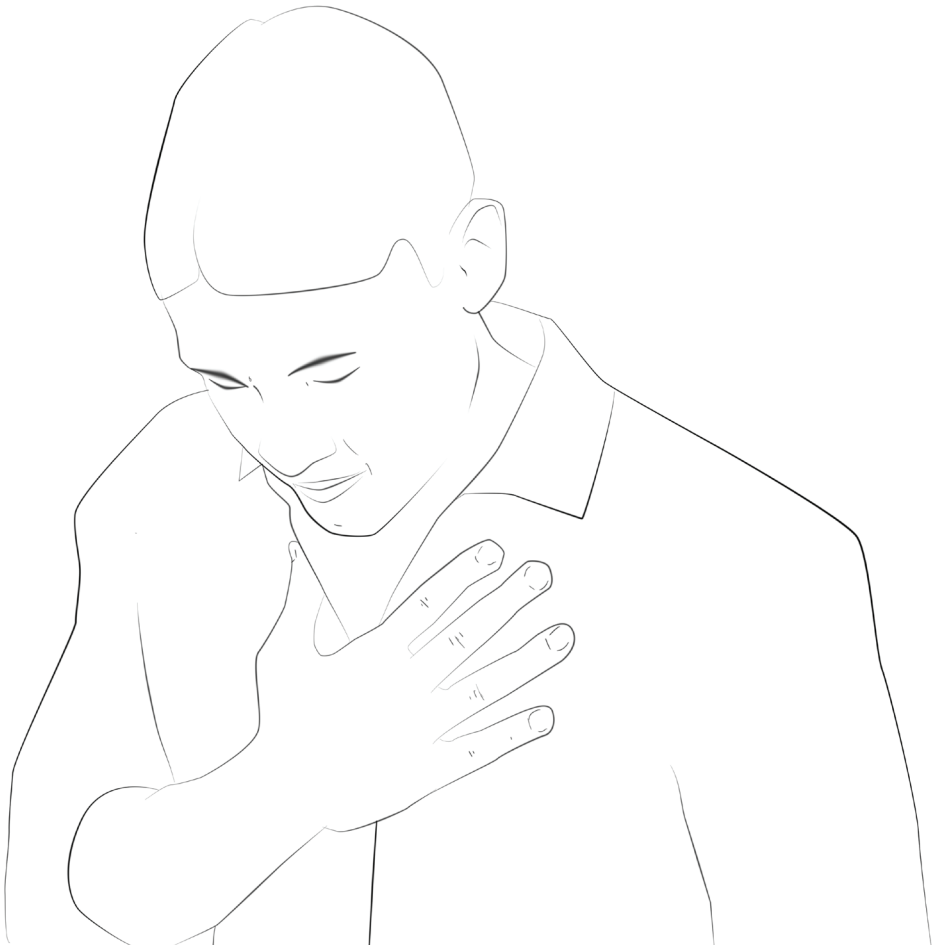


Figure 35. situation at home



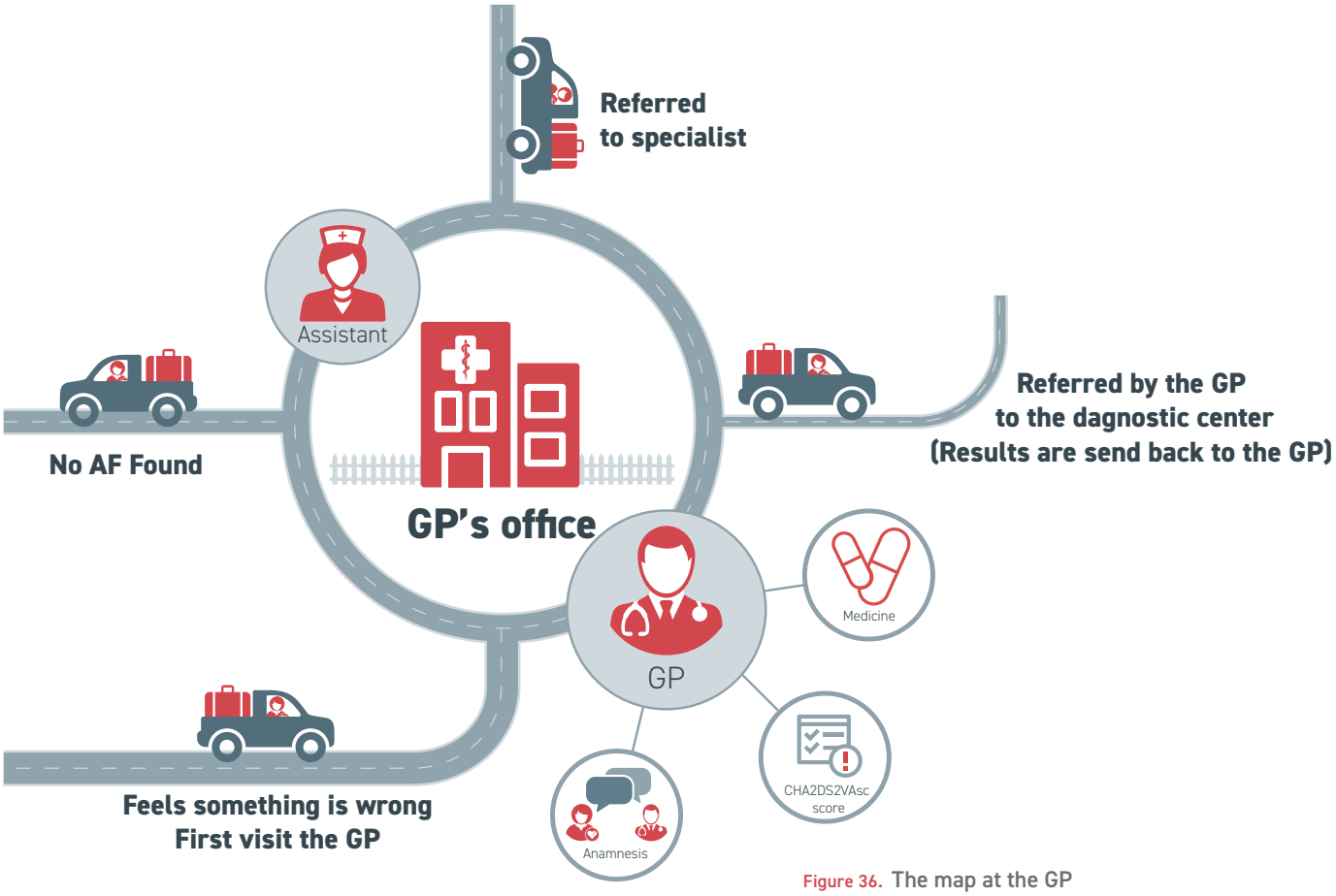


Figure 36. The map at the GP

2.4 JOURNEY TO THE GENERAL PRACTITIONER

The first real chance of detecting if a patient has AF is during a consultation with the GP. If a patient presents with complaints related to cardiovascular diseases, a GP will, as a minimum, listen to the heartbeat. From a certain age, GPs will also take the patient's blood pressure in order to screen for AF.

However, the vague nature of the complaints and symptoms related to AF make it easy for a GP to miss AF, in particular paroxysmal AF. It is hard to determine AF by an anamnesis alone, although the conducted interviews Showed that the main way of diagnosing AF for the GPs is solely by anamnesis. The reason behind this could be that the step of referring a patient to a cardiologist is too big and diagnostic centres for this kind of diagnosis are not in the mind of the GP.

This becomes especially evident when considering how many patients are predicted to have AF when compared to how few patients the GPs see that present with AF. Furthermore, the interview indicated that GPs believe it good practice to mainly diagnose AF when it is already permanent or persistent, they are not aware in the implications of a later diagnosis.

This conviction stands in stark contrast to the overwhelming opinion of the cardiologists interviewed, that AF can only be diagnosed by recording an episode. The cardiologists also press the importance of early detection.

The difference between GPs and cardiologists might be explained by the background of the GPs and their experience with AF,. The GPs interviewed either lack experience with AF all toghether, or only have experience with permanent AF in seniors.

The challanges can result in that a patient has to visit the GP multiple times before they have the right diagnosis or are refeered to the cardiologist.

2.4.1 Goals of the GP

A GP is the doctor that is 'embedded' within a local community. The GP has a very broad-based knowledge of the full spectrum of medical, psycho-medical and social, issues of a patient, but lacks the in-depth knowledge of a specialist. In the Netherlands, a primary role of a GP is to be the filter for the specialists, only referring cases in which the GP does not have the necessary in-depth knowledge Alleviating the specialists and hospitals with the burden of the cases that do not require this level of specialisation. [Figure 38]

Figure 37. GP taking bloodpressure while listening to the heartbeat of a patient.

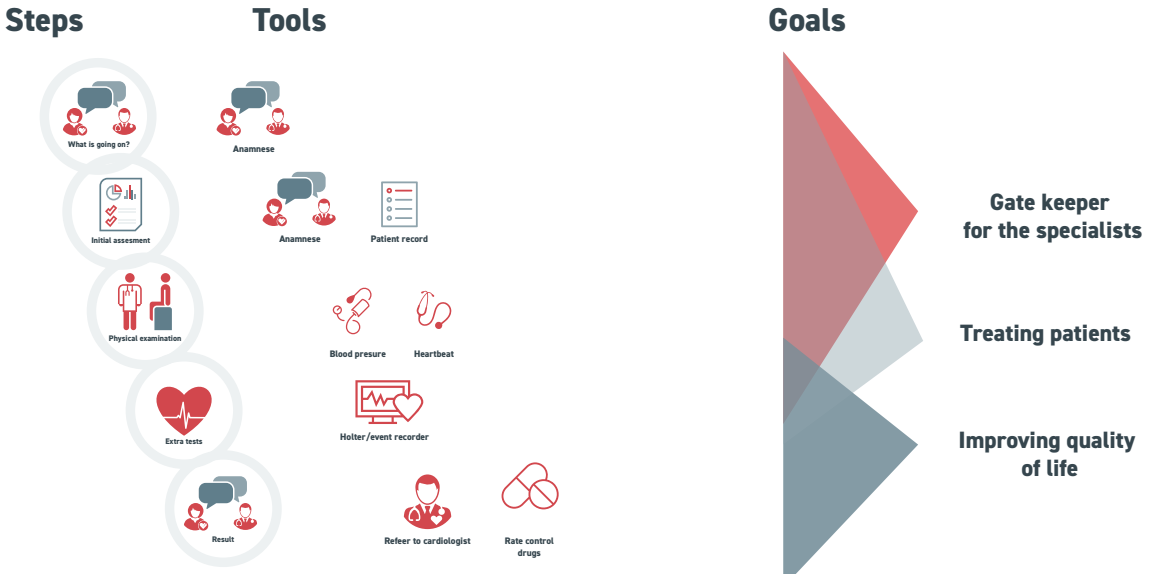


Figure 38. Steps that a GP uses to reach his goals

2.4.2 Decision path at the GP

The GP will start a consult with an anamnesis [Figure 39] [Figure 40]; this is the process of asking a series of specific questions aimed at gaining useful information to formulate a diagnosis. In a sense, it can be considered as a detective looking for clues where to look next and finally to catch the culprit.

The answers from a patient provide these clues. However, a GPs consult is typically also conducted under time pressure. The consults only take about 10 minutes, of which the GP spends 4 minutes on administrative purposes. Whilst GPs are trained to work at this fast pace, patients are not. The lack of a patient's ability to quickly tell the right story, creates a real possibility for a scenario in which the GP is not able to get the full story from a patient. (Boekraad, 2017)

If the GP suspects an arrhythmia or the patient is above the age of 67, the GP will conduct a simple physical examination, consisting of measuring the patient's blood pressures and listening to the heartbeat. If the GP hears an arrhythmia, the decision is made, depending on the patient, to refer to a cardiologist or start treatment without specialist intervention. If the GP does not find anything from the physical examination, yet still suspects something is wrong, he or she can decide to order further tests. With the results from these, the decision is made to either refer the patient to a cardiologist, start treatment directly, or to dismiss the patient.

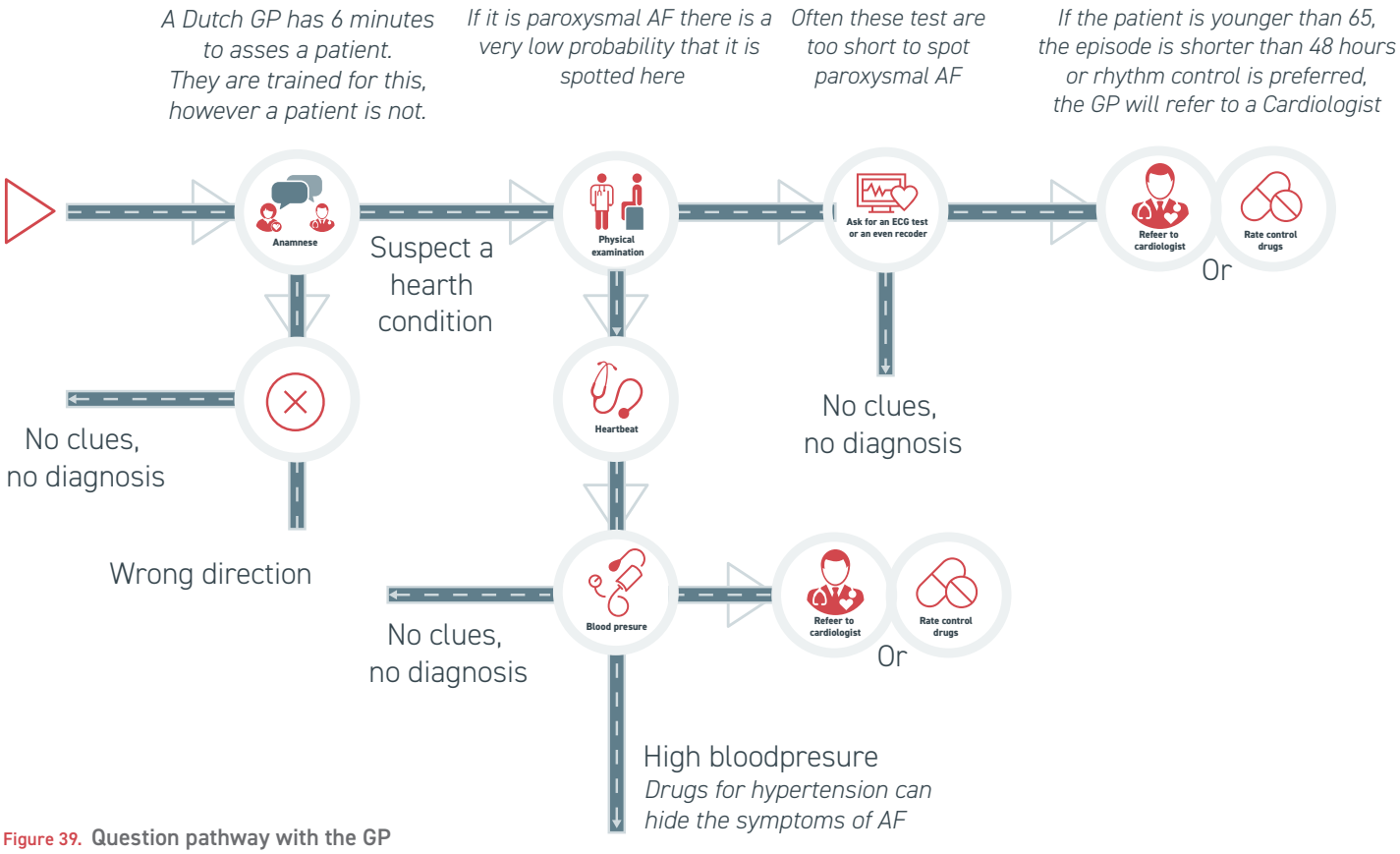


Figure 39. Question pathway with the GP

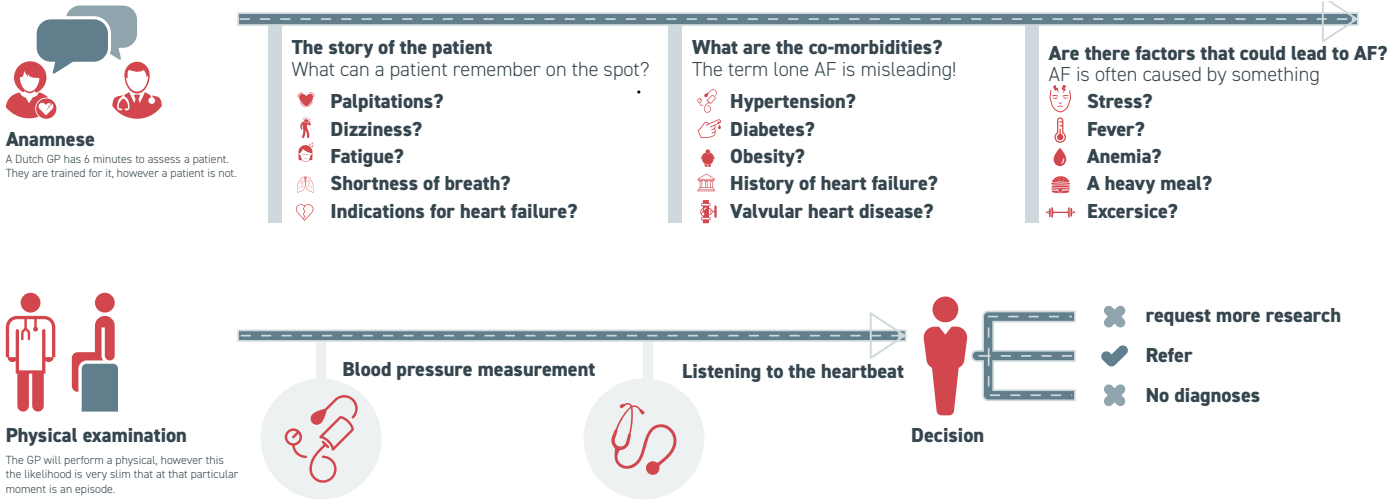


Figure 40. Questions of the anamnesis.

2.4.3 Needs of the GP

On a daily basis, the GP is overwhelmed with information. The modern patient is well informed and has often already collected an array of information. Often, the source of this data is distrusted, wrong, or incomplete, thus the GP does not see a need for the patient to collect the data. Besides, Many GPs would rather have a clear overview of the processed results than that having to read and interpret the 'raw' data stream.

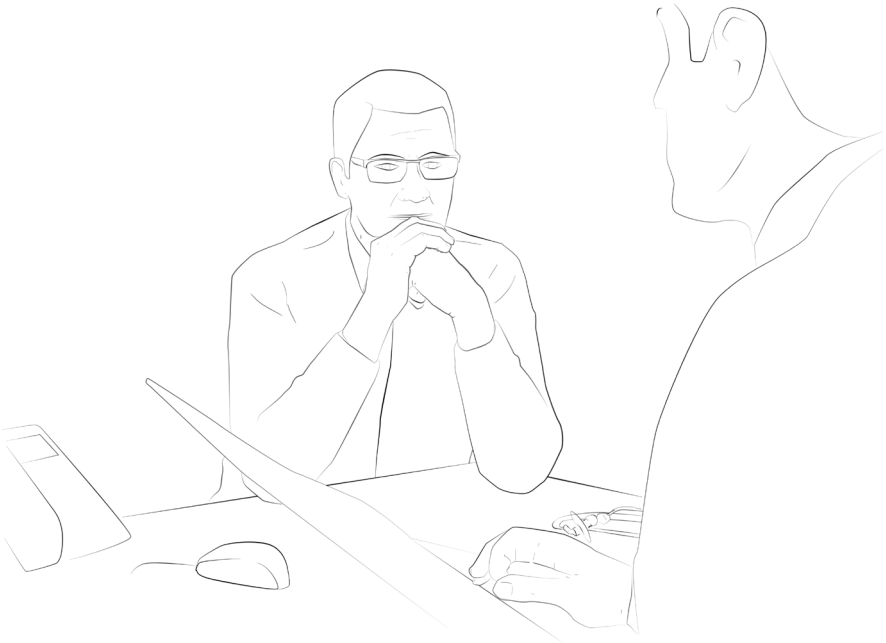


Figure 41. Anamnesis taken by the GP

2.5 CARDIOLOGIST

When referred, a patient will visit a cardiologist [Figure 42], possibly an electrophysiological cardiologist. A typical cardiologist is a specialist on the heart in general; the electrophysiologist is specialised in electrical functions of the heart.
Where a GP only can prescribe anticoagulant and rate control drugs, cardiologists can also start rhythm control drugs and perform a cardioversion. An electrophysiological cardiologist can also perform ablation therapy. Figure 43 explains the path of the cardiologist. Often these treatments are not succesful and have to be repeated, a suspected reason behind this(as discussed in chapter one) is the progressive nature of AF and the re-modelling of the atria. This can result that a patient has to undergo multiple cardioversions and ablations. Because AF is easier to treat in the early phases of the disease cardiologist believe firmly that early detection is nescarry. The interview cardiologists believe that a better monitoring or screening process already at the GP could lead to better results in treatment and fewer strokes.

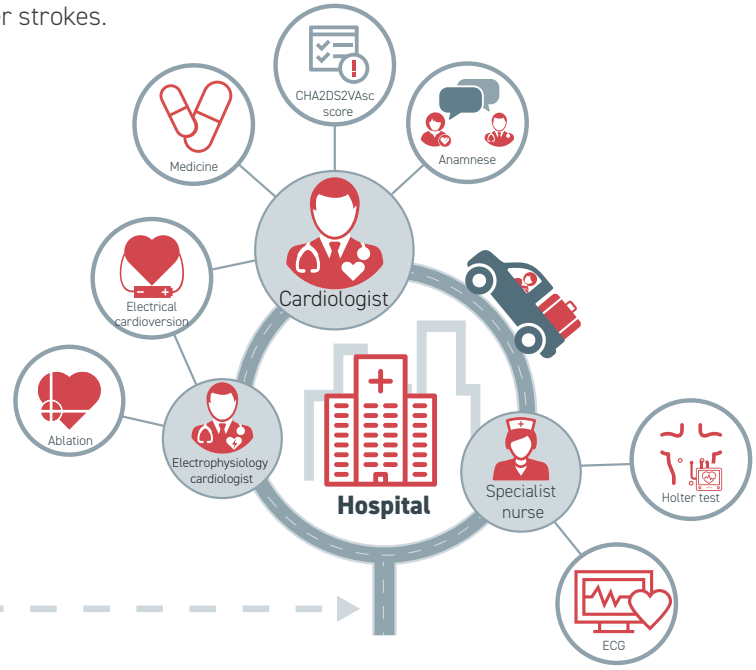
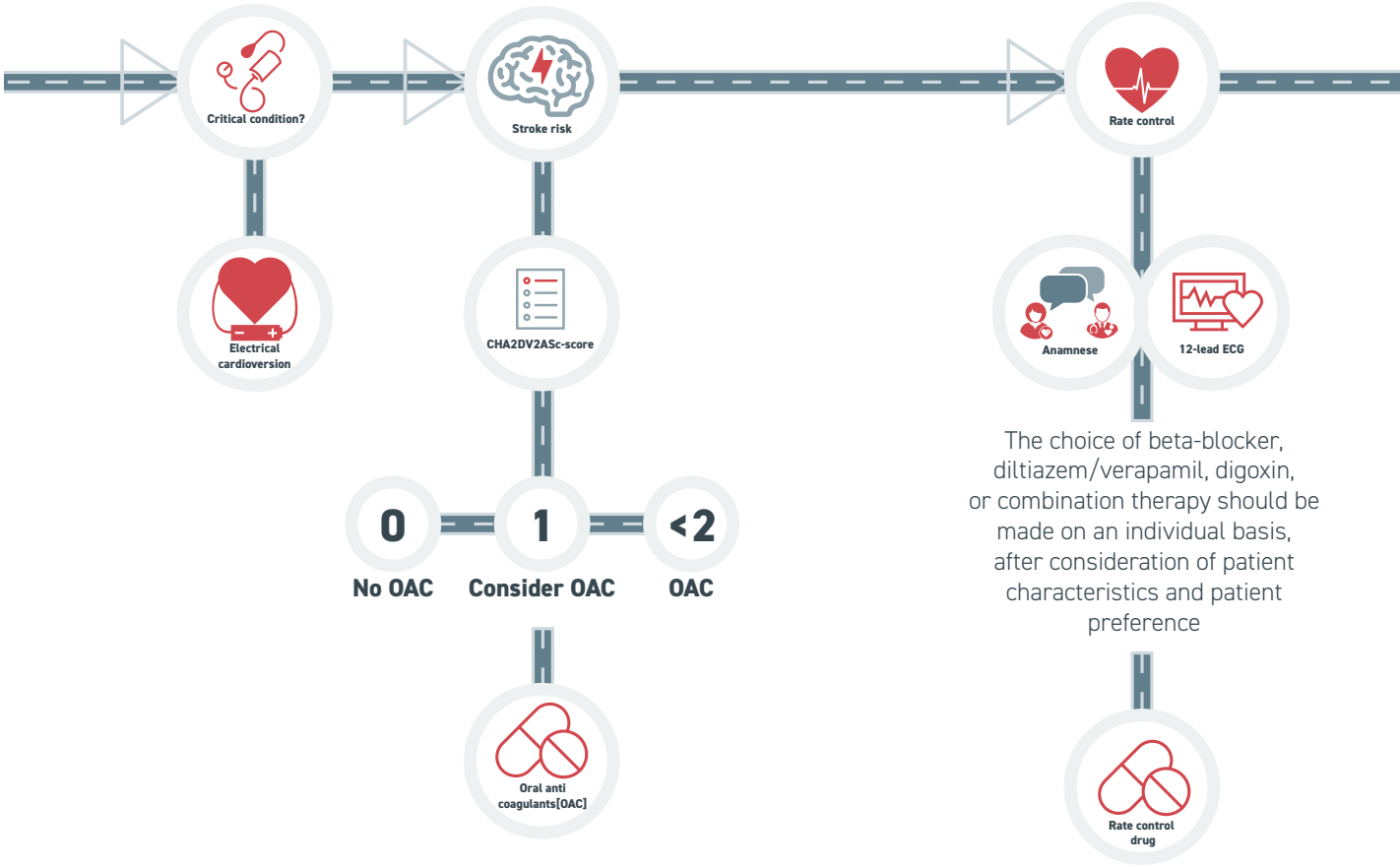


Figure 42. Map at the Cardiologist



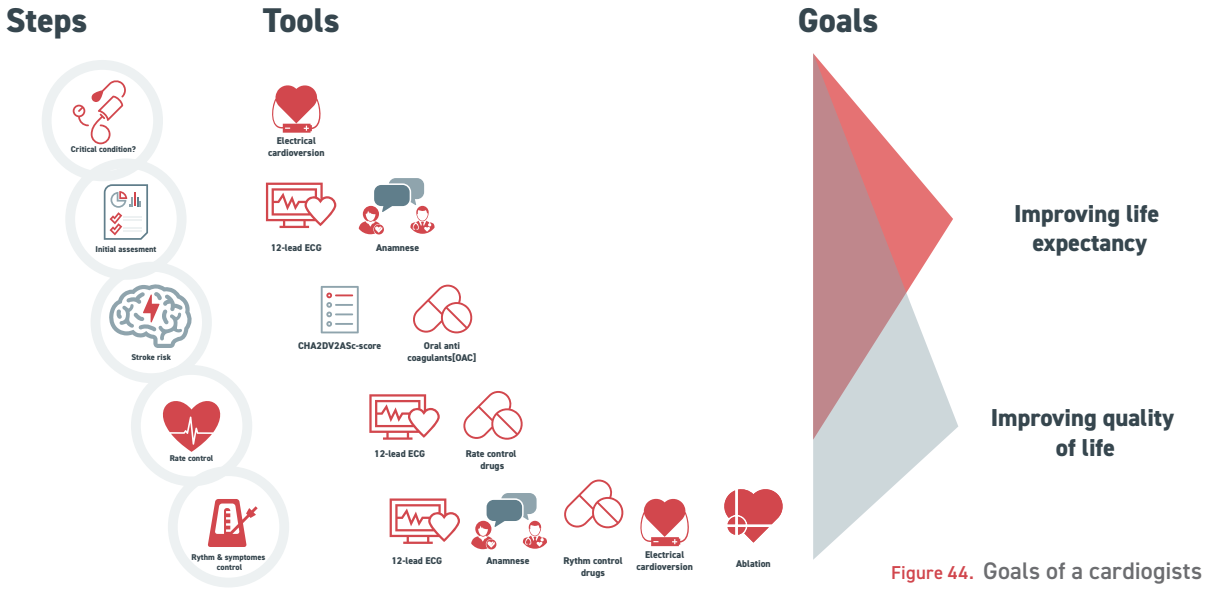


Figure 44. Goals of a cardiogists

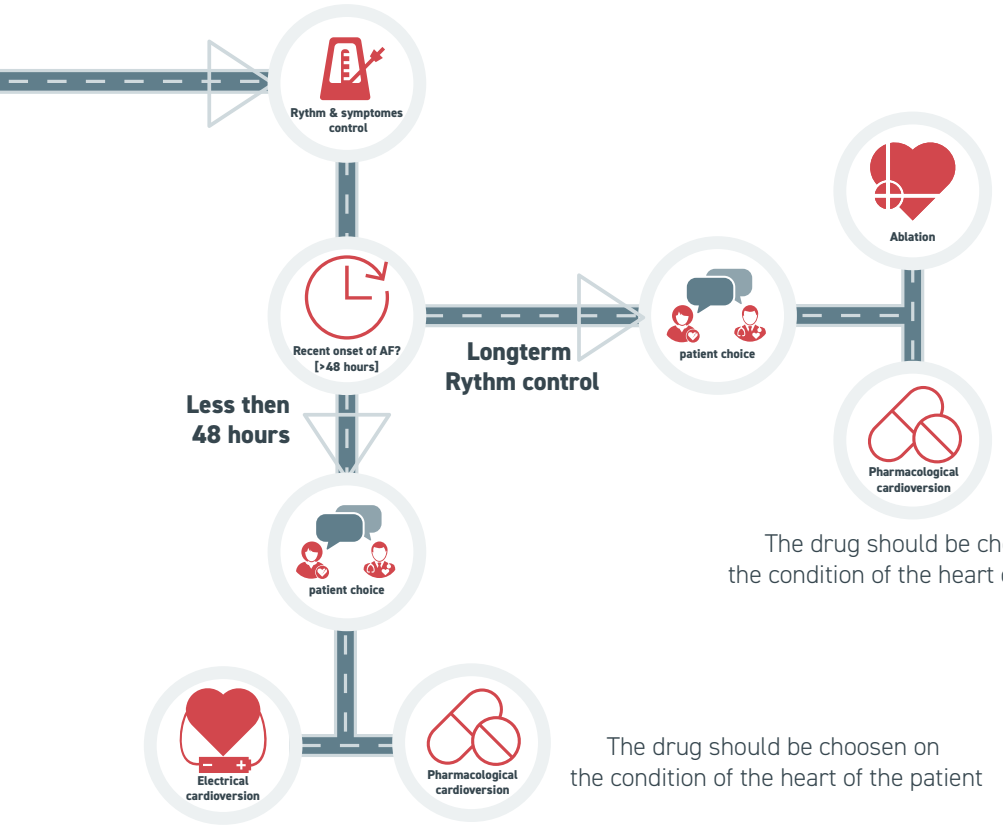
2.5.1 goals of a cardiologist

The primary objective of a cardiologist is improving the life expectancy of a patient[Figure 44]. This is usually achieved by prescribing anticoagulant if needed (depending on the CHA2DV2ASc score) and reducing the heart beat rate below 110 beats per minute [BPM]. Once this has been achieved, improving the quality of life becomes the main aim of the treatment. This is mainly achieved by reducing the symptoms of AF, for instance through cardioversion, rhythm control drugs and ablation therapy.

2.5.2 Needs of a cardiologist

The needs of a cardiologist stand in high contrast to those of the GP. Where the GP could be overwhelmed with information, having to filter out the relevant parts, the cardiologist has a need for more information. A cardiologist has the final responsibility for the treatment process of a patient, whereas a GP does not. As a specialist, it is expected that a cardiologist is able to conclude on a diagnosis by him/herself. Therefore, even if a system is smart and an algorithm can make the test diagnosis, the cardiologist might still want to look at the 'raw' data to ensure if the algorithm is correct.

From the interviews, it became apparent that the cardiologist generally trust the data from GPs, as long as they can see the 'raw' data, however, due to many different systems being in use, it is impossible to upload data from the GP into the hospital's system.



The drug should be choosen on the condition of the heart of the patient

The drug should be choosen on the condition of the heart of the patient

Figure 43. Path for treatment at the cardiologist.

2.6 CONCLUSION

n the journey of the patient it becomes apparent that there is not one journey, from the diagnosis to the ablation therapy, everything often has to be done again. Also, it becomes evident that AF 's hard to diagnose in the first stages of the disease due to short episodes that can be difficult to measure and vague symptoms. This is a major problem for the treatment of AF, where the highest success rate is when the heart is still relatively healthy and not jet re-modelled.

A large difference between what the GP needs and what the cardiologists needs is also observed. One thing is sure from the cardiologist perspective, monitoring is useful also for the GP, especially when this leads to early detection.

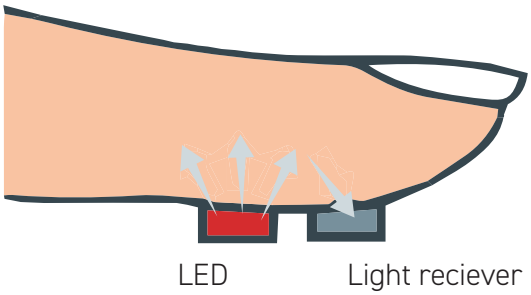
The next question is: are PPG and the Philips Health Watch up for this task?

3. - DETECTION TECHNOLOGY

The focus of this graduation project is Photoplethysmogram (PPG) technology. It was decided to focus on this technology because of the unobtrusive nature of the technology and the algorithms that Philips has recently developed to detect Atrial fibrillation with PPG. PPG is in a senseessence a LED that shines light on the skin, with the light reflecting into a light sensor. The reflection has small, yet noticeable changes that correlate with the pumping action of the heart. To design for this technology, some knowledge is required about the working principle, the signal, the (possible) applications of PPG as well as its limitations.

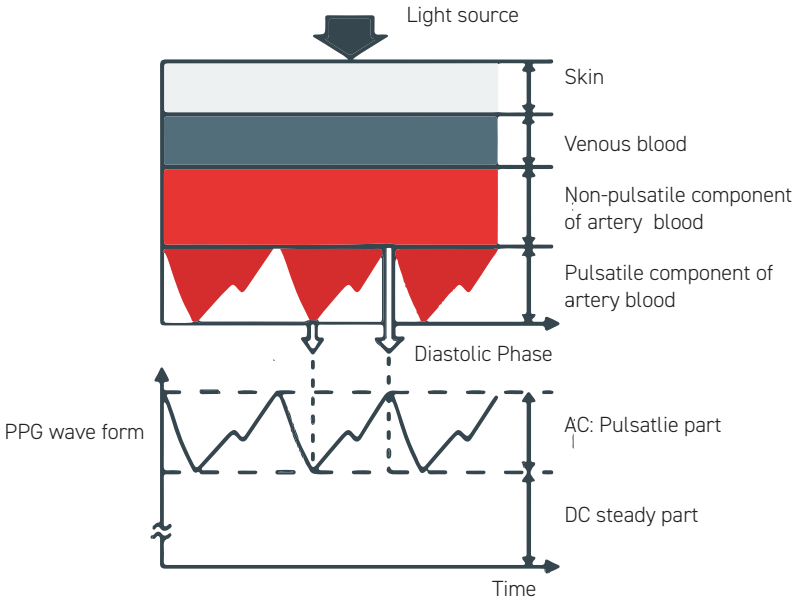
3.1 PHOTOPLETHYSMOGRAPHY [PPG] - WORKING PRINCIPLE

PPG is the sensor used in the Philips Health Watch. PPG. It uses light to measure the reflectiveness of the blood in the skin. Light is sent from a LED through the skin and reflected into a light sensor (Figure 45). Light travelling through tissue can be absorbed by different substances, including pigments in the skin, bone, and arterial and venous blood. Most changes in blood flow occur in the arteries and arterioles (these are not the veins). For example, arteries contain more blood volume during the systolic phase of the cardiac cycle (the highest pressure of the heartbeat) than during the diastolic phase (lowest pressure of a heartbeat). PPG sensors optically detect these changes in the
blood flow volume (i.e., variations in the detected light intensity) in the microvascular bed of tissue via
reflection from or transmission through the tissue (Tamura, Maeda, Sekine, & Yoshida, 2014). These changes relate to the different phases in the waveform of the PPG signal as seen in Figure 46.



Source: (Tamura, Maeda, Sekine, & Yoshida, 2014)

Figure 45. PPG Sensor



Source: (Tamura, Maeda, Sekine, & Yoshida, 2014)

Figure 46. PPG signal working principle

3.1.1 PPG signal

A crucial difference between an ECG and a PPG signal is that an ECG records the electrical activity of the heart, whilst a PPG signal records the effect of the pumping action of the heart.

This difference could be both an advantage and a disadvantage of PPG: while an ECG measures directly from the heart, a PPG signal contains somewhat different information than a 12-lead ECG. The difference in information is because of a PPG signal measures the blood volume, which is a result of various factors and which is closely related to blood pressure measurement.[Appendix A] Of course, more information also means a higher number of factors that could skew the results.

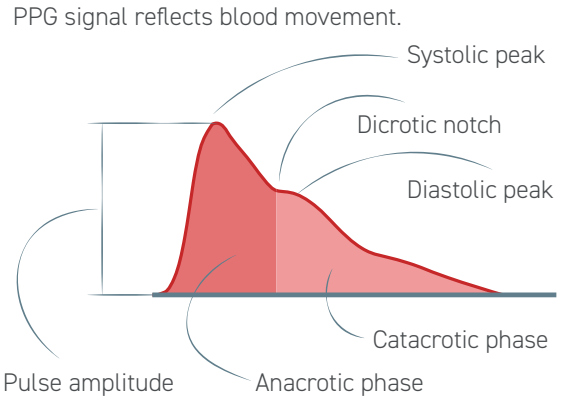


Figure 48. **PPG waveform**

3.1.2 Heart rate for a PPG signal

By finding the systolic peaks and measuring how many peaks there are in a minute, BPM can be found(-Figure 49)

The heart rate interval or interbeat interval is found by measuring the time between systolic peaks. These are often plotted in a Poincare plot/ Lorenz plot. (Figure 47)

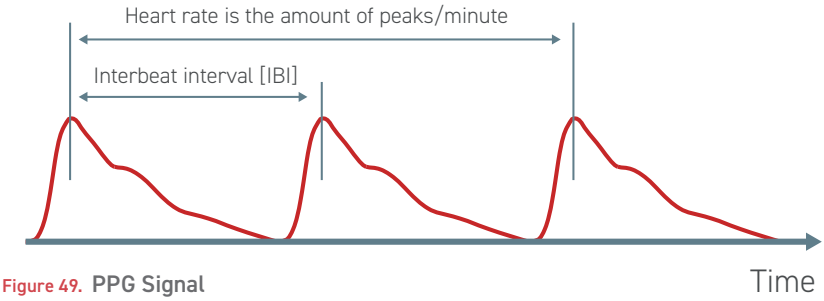


Figure 49. **PPG Signal**

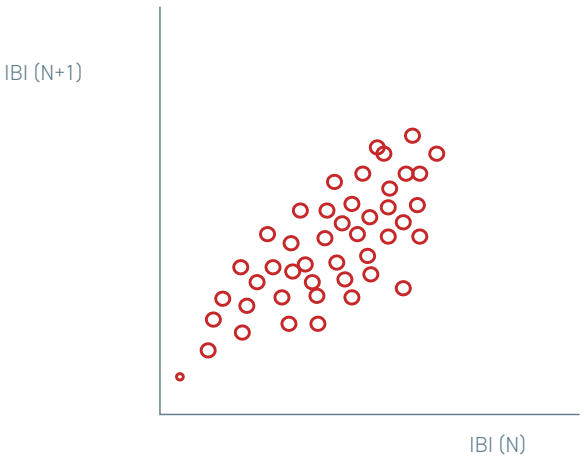


Figure 47. **Example of a lorenz plot**

3.1.3 Atrial Fibrillation detection with PPP

A Lorenz plot is a scatter plot that shows an interval as a function of the preceding interval. In this case that means it shows each interbeat interval (the time between beats) versus the preceding one. It can distinguish AF from other atrial arrhythmias such as atrial flutter, where the ventricular response is not as irregular as in AF as seen in Figure 50. The pattern of AF is highly random while the pattern of atrial flutter is more focused.

At Philips, a first-order 11-state Markov model, is used to calculate the probability of AF given the irregularity of the pattern in the inter-beat time series (Bonomi, et al., 2016). The flow of this system is illustrated in Figure 51.

While the algorithm (and therfore the Markov model) to identify AF is not the focus of this graduatin report, it is insightfull to know what a Markov model is; "A Markov model is a stochastic method for randomly changing systems where it is assumed that future states do not depend on past states. These models show all possible states as well as the transitions, rate of transitions and probabilities between them.

Markov models are often used to model the probabilities of different states and the rates of transitions between them. The method is used to model systems. Markov models can also be used to recognise patterns, make predictions and to learn the statistics of sequential data."("What is Markov model?", 2017)

3.1.4 Challenges with PPG

The primary challenge with this type of detection is that the artifacts from movement between the skin and the sensor look very similar to AF. To ensure that the algorithm generates only a small number of false positives, the motion data is also captured. If a specified time interval of PPG data coincides with too much movement, it is rejected. In order to evaluate the movement data, 30 second intervals are used, as can be seen in Figure 51

3.1.5 Coverage and Atrial Fibrillation detection

TThe primary goal of this project is to support the GP and the cardiologist in discovering AF, especially in the early stages, when episodes are brief and difficult to detect. Detecting these is of significant value because of the larger number of treatment options and higher success rate of early treatment of AF. (Kuipers, 2017).

To be able to achieve early detection, there is a need to achieve high coverage. Coverage is the time that the PPG sensor can get valid and sound data. As discussed before, the algorithm will not use data that may be corrupted by artefacts from movement, which is a challenge on the wrist, due to the amount of movement there during the day.

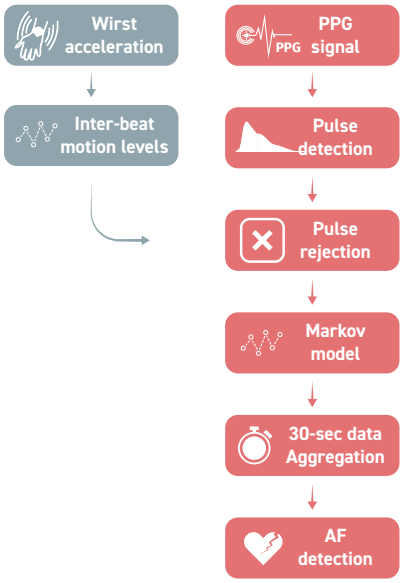


Figure 51. Block model of the algorithm for a PPG mounted in bracelet or wrist watch

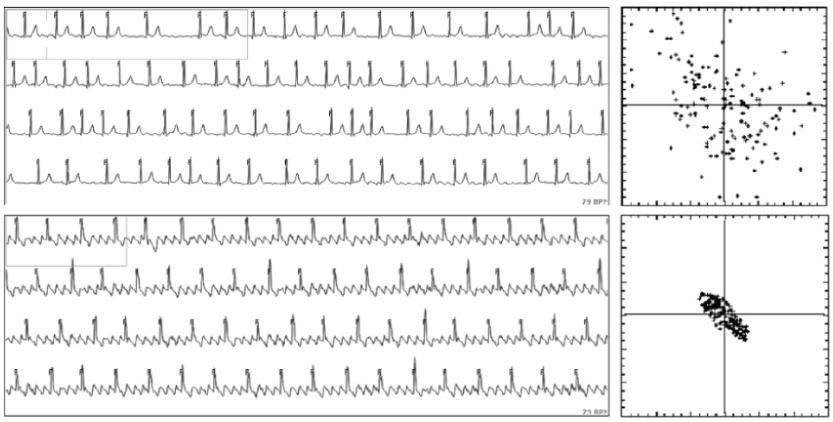


Figure 50. Above: episode of atrial fibrillation on the ECG with corresponding Lorenz-plot, Lower: episode of atrial flutter on the ECG with corresponding Lorenz-plot

3.2 FIRST TEST TO IMPROVE COVERAGE: WRIST - TO UPPER ARM

The project started out with the Philips Health Watch, equipped with a PPG sensor, as a candidate for the AF detection instrument. Because the Health Watch is placed on a patient's wrist, it is susceptible to movement, especially since the wrist is one of the body parts that move the most during the day.

To find out of if this was a real problem, a test was conducted together with a researcher from Philips (Jos Gilissen). In this test, we compared the data from a wrist-worn device to a device that was placed on the upper arm with an improvised strap for 12 hours. From the test, it soon became apparent that the wrist was not very suitable if a high coverage is required. It was also found that the upper arm provides a much-improved coverage.

In figure Figure 52 and Figure 53, this effect can be seen from the increased amount of data in the respiratory rate (i.e. the number of in/exhalations per minute) of the data from the upper arm compared to the data from the wrist. The algorithm for respiratory rate needs a lot of 'good' data before it can be calculated, just like the algorithm for AF. The increased amount of 'good' data from the upper arm will probably also increase the coverage during the day compared to the wrist.

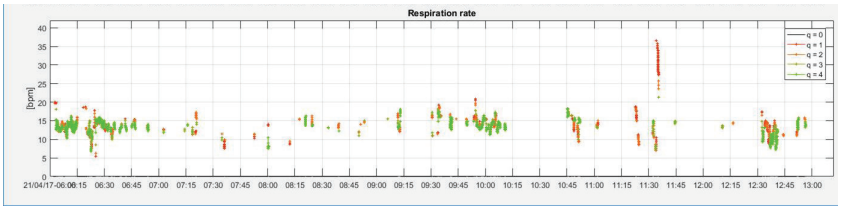


Figure 52. **PPG data from wrist**

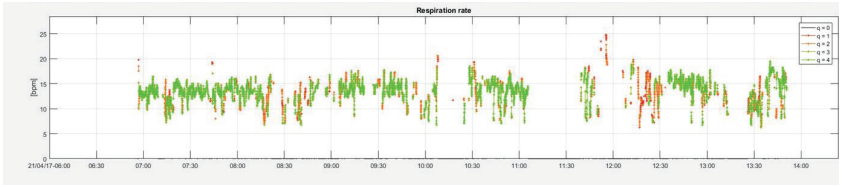


Figure 53. **PPG data from upper arm**

3.2.1 Philips Health watch.

From the above, it may be concluded that the wrist is not a suitable place for AF detection. Building a system around the Philips Health Watch is possible[Figure 54]. However, the coverage will be meager. Philips researchers believed that coverage would be around 60% during the day (Bonomi, 2017).

However, according to three of the interviewed cardiologists this coverage is too low to effectively detected paroxysmal AF and to determine the burden of AF. ("prof. dr. I.C. van Gelder", 2017)("Dr N M S de Groot", 2017)("dr. J. de Groot", 2017).

Figure 54. **Philips Healthwatch**

3.3 BUILDING A PPG-BASED SENSING DEVICE

To better understand the characteristics of PPG, a test was setup to create a dedicated PPG-based sensing device. The PPG sensor of DFRobot is a relatively easy to use PPG sensor[Figure 55] that connects to an Arduino which can display a plot of the data, in this case, the waveform from the PPG sensor's output.

Originally the DFRobot PPG sensor comes with an elastic strap for use it on a finger or wrist. To test how the sensor behaves at different locations on the body[Figure 56], the elastic strap was replaced by adhesive tape[Figure 57]. Various locations were selected: one on the underarm, two on the upper arms and three on the chest under the clavicle bone.

Although it became quickly clear that none of these locations was as sensitive to movement as the first, there were small differences. To further explore this, the signal was examined when doing a little test: typing. It was found earlier that typing renders the PPG signal useless when the sensor is on the wrist.

This test was very preliminary, and it did not strongly discriminate between the signals from the different locations. At this stage it was still difficult to say which is the best. However, it was clear that, while typing, the signal form all of these locations was better than that form the wrist. (Figure 58 vs. Figure 59)

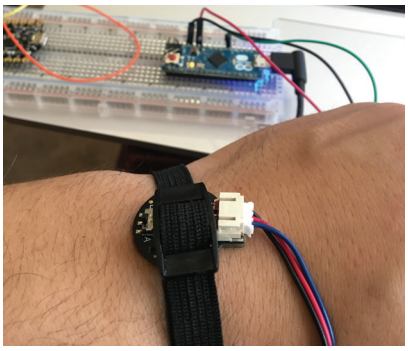


Figure 55. PPG sensor of DFRobots

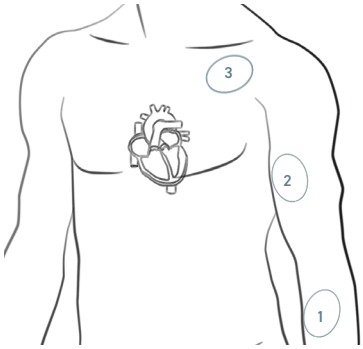


Figure 56. Locations for the tests

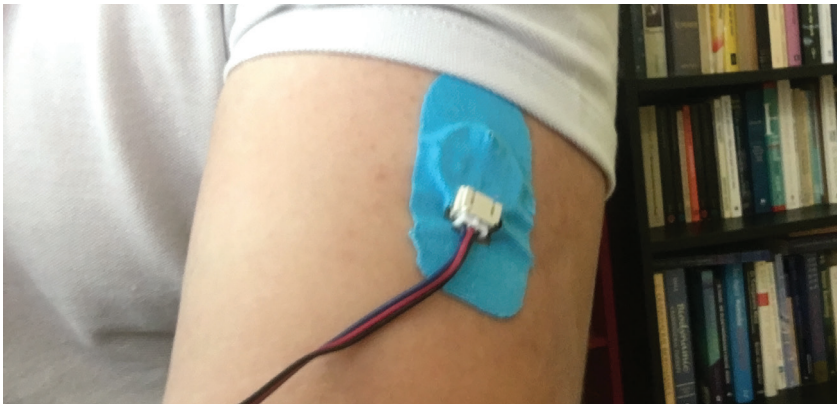


Figure 57. PPG sensor attached to the upper arm

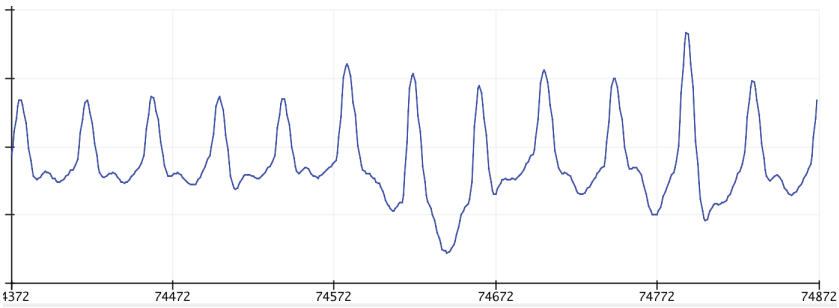


Figure 58. PPG signal upperarm

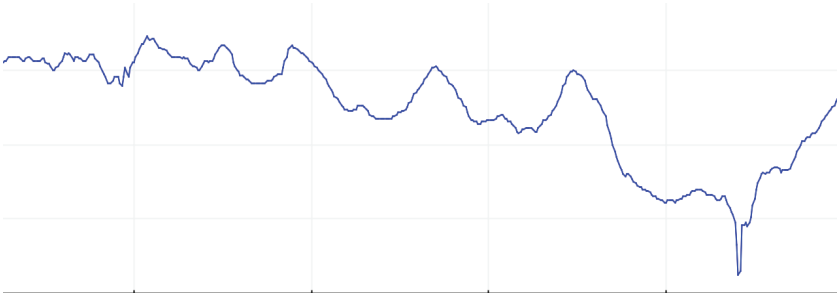


Figure 59. PPG signal wrist

3.4 OUTCOME FROM THE TESTS AND CONCLUSION

The starting point for this graduation project was the Philips Health Watch; however, it became apparent that the watch is not suitable for an AF detection support system. Movement artifacts would result in too much valuable data being dismissed. The upper arm is a better place. Movement artifacts are less here, in comparison to the wrist, whilst the user is still able to interact with the device.

A single lead ECG in combination with a PPG may provide exciting possibilities, such as bloodpressure [appendix A]. However, for the diagnosis of AF alone, a single lead ECG would not have any extra value in combination with a PPG sensor. This is because a single lead ECG and a PPG sensor have the same overlap in collected data [Appendix B].

To better understand what the market needs are and how the product could be best positioned, more information is required on existing products. This will help to answer the question "Where could a product utilising a PPG sensor be of most value as a method for AF detection compared to the existing products?"

4 - COMPARISON OF EXISTING PRODUCTS

This chapter, provides is a short overview of the Artrial Fibrilation detection devices currently on the market. Due to the arrival of new technologies, the exsting products consists of both 'old' players (holters, Reveal Linq and ECGs) as well as new entrants. (Smartwatches, PPG by smartphone camera and signal lead ECGs) (Figure 60)
In order to analyse the existing, the products can be divided into two groups. On the one hand, there are the spot check detectors, on the other the continuous monitoring type detectors. A distinction can also be made between the consumer-aimed products and the professional-aimed products.
Spot checks are cheaper than the currently available solution for continuous monitoring. However, the chance that an asymptomatic patient is missed with these spot checks is high.
Professional-aimed products are, for example, the12 Lead Electrocardiography (ECG) and holters. These are medical grade devices that measure the electrical activity of your heart from different places on the body.

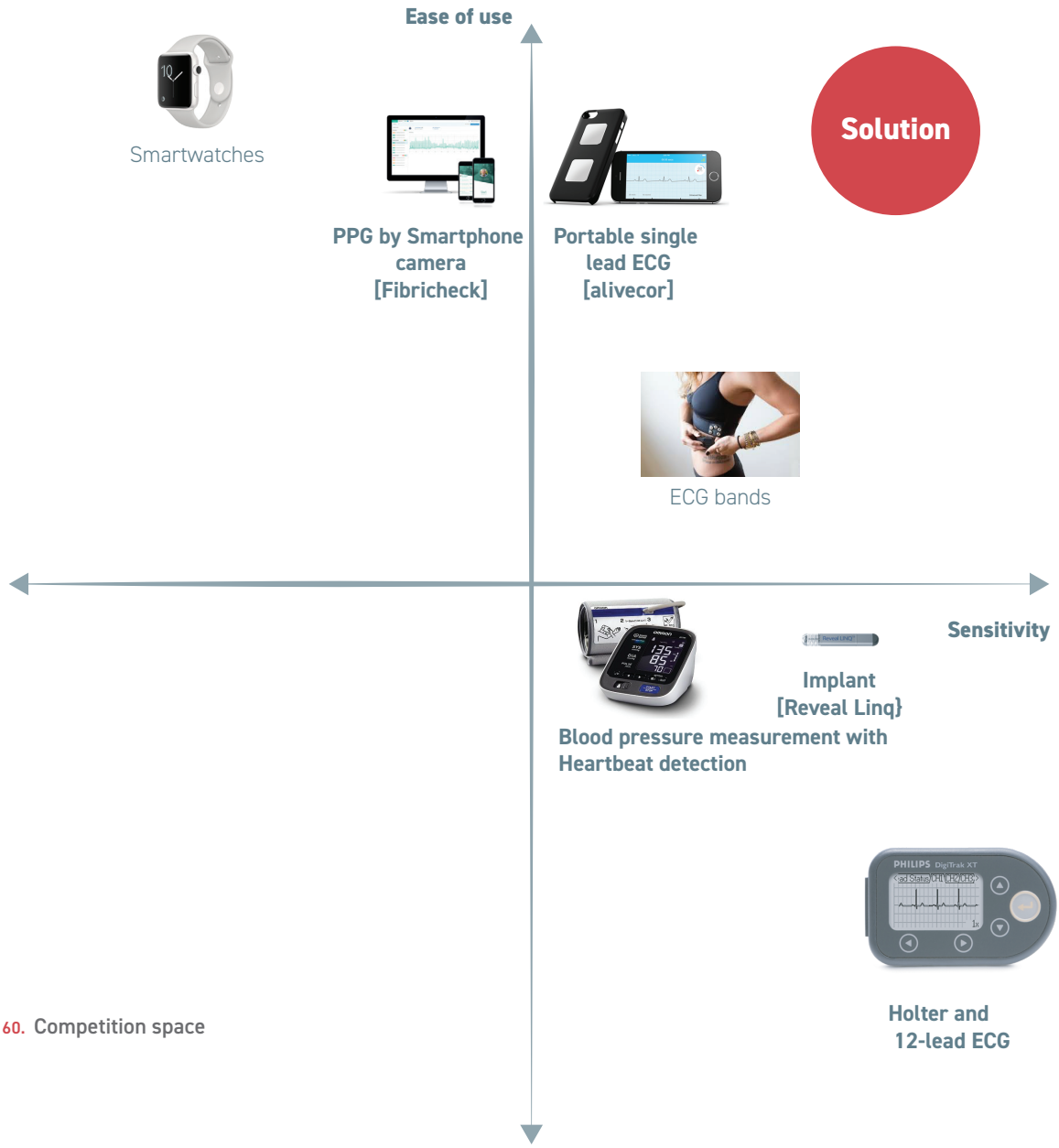


Figure 60. Competition space

4.1 PROFESSIONAL-AIMED PRODUCTS

By product type, the professional market for heart monitoring devices is classified into holter monitors, resting ECG systems, stress ECG monitors and ECG bands (Grand View Research, 2016). However, for the purpose of this report, these products are all grouped together. They are highly accurate, and the cardiologist can see much more than only the arrhythmia. However, an ECG[Figure 62] is only a measurement of a few minutes, while a holter[Figure 61] can be used for up to 7 days for diagnostic purposes. Nonetheless, monitoring is almost never carried out over such a long period. Generally, the monitoring is only prescribed for a period of up to 24 hours.

While ECG devices are needed to find the underlying cause of atrial fibrillation, they are not necessary to detect and diagnose atrial fibrillation. You could say that these are 'too good' to be used only for monitoring and diagnosing AF.

Some of the major players in the global diagnostic electrocardiograph market are (Grand View Research, 2016):

- GE Healthcare,
- Schiller AG,
- Spacelabs Healthcare,
- Philips Healthcare,
- Cardionet, and
- Mortara.

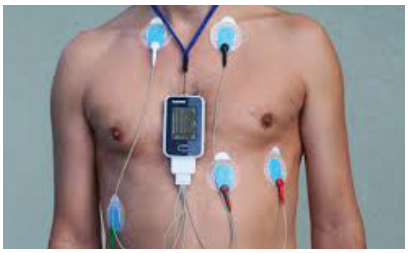


Figure 61. Holter

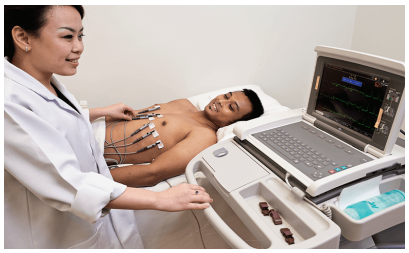


Figure 62. 12 lead ECG

4.2 SEMI-PROFESSIONAL SPOT CHECK

Modern blood pressure measuring devices[Figure 63] can also detect arrhythmia, however it is still a spot check. These devices are rarely used at home. Many of the players in the ECG market also provide blood pressure measuring devices, including Philips. These devices cost around 100 dollars.

Figure 63. Bloodpressure measuring device from Omron

Figure 64. Reveal Linq from Medtronic

4.3 PROFESSIONAL CONTINUES MONITORING

The Reveal Linq[Figure 64] by Medtronic is an implantable device that sits under the skin in the chest of the patient. It is not easy to use and costly. Therefore it is only used for monitoring and not for regular diagnostics of atrial fibrillation. A Reveal Linq costs thousands of dollars.

4.4 CONSUMER SMART PHONE SPOT CHECK SOLUTIONS

4.4.1 Kardia from AliveCor

The Kardia is a small patch[Figure 65] with a single lead ECG that fits on the back of a smartphone. It allows recording of a simple ECG and sending the results to a healthcare professional. The system makes the discussion between doctor and patient easier when somebody suffers symptoms of arrhythmia. This device is only effective when the patient suffers from symptomatic AF because the patient is only required to measure when they feel an episode.

Figure 65. Kardia from AliveCor

4.4.2 Fibricheck

Fibrickeck[Figure 66] is similar to Kardia. However, it uses PPG technology (PPG is discussed in Chapter 3), utilising the light and camera of a smartphone. Fibricheck has the same disadvantage as Kardia; it is only effective with symptomatic AF.

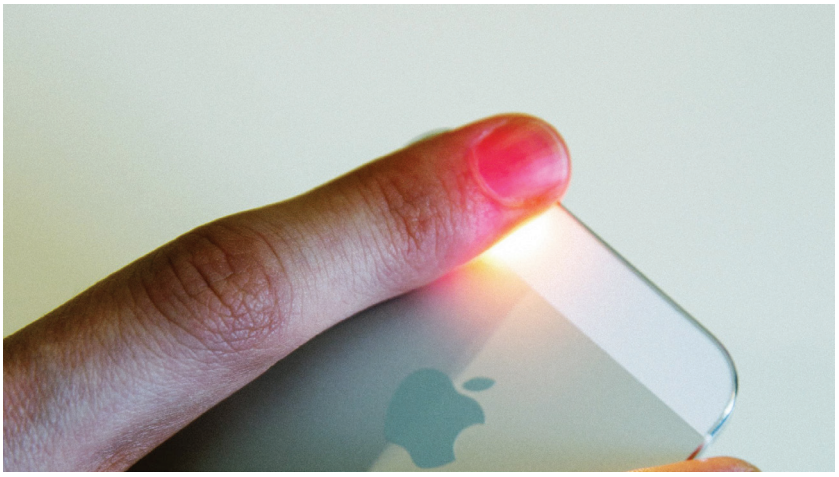


Figure 66. How to use Fibricheck

4.5 CONSUMER CONTINUOUS MONITORING SMARTWATCHES

Cardiogram[Figure 67] is an app that uses the Apple watch to measure your heartbeat. The developer of this app is now developing an algorithm that uses the same measurement and data to detect AF. (Chen, 2017))

Figure 67. Cardiogram & Apple watch

4.6 CONCLUSION

As seen there are competing products on the market for AF detection that are either unobtrusive or accurate or long-term monitoring, yet, none of these products combines all of these qualities in a holistic product. In addition, none of these products is specifically aiming at deployment by the GP, which is where it could have the biggest impact.

PART II
CONCEPTUALIZATION

As the next step in the overall design process, the insights gained in the analysis phase now have to transform into ideas by connecting the various elements. This phase is called the synthesis [Figure 68].

The synthesisphase will lead to the choice of a design direction, followed by a design brief that specifies the requirements for the design. With this design brief, a concept will be developed in the ideate phase.

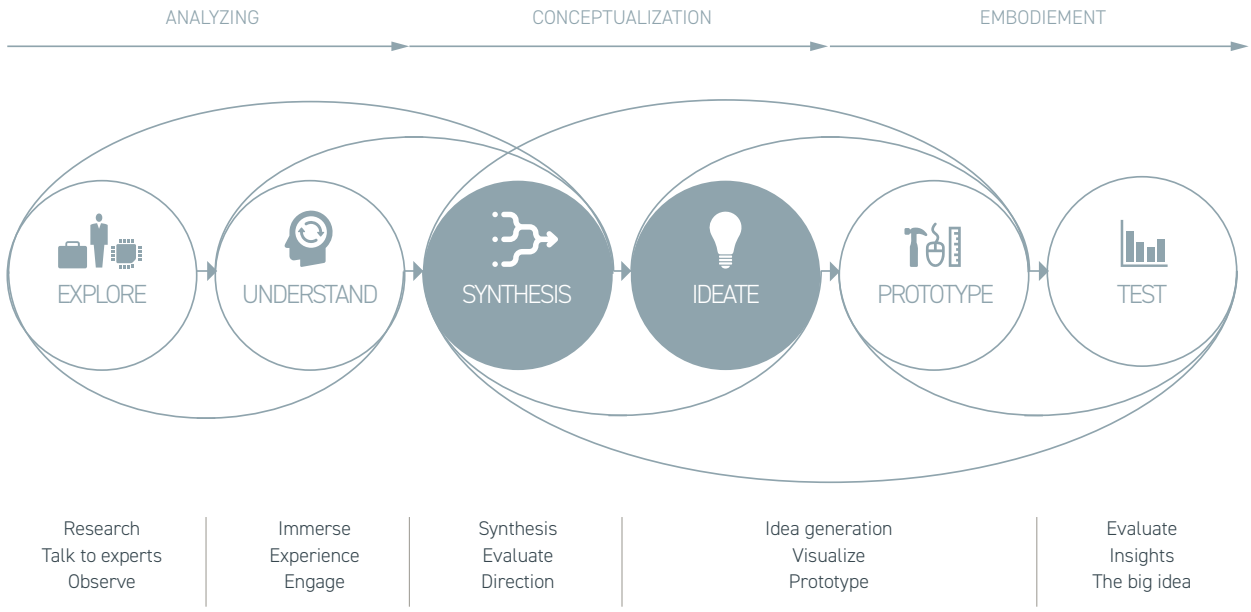


Figure 68. Conceptualization phase

5. - DESIGN DIRECTION

The primary goal of the synthesis phase, within the conceptualization, is to use the understanding and knowledge gained in the first phase to define the problem and generate a solution for this. This is done by considering all the separate pieces of information gained in the analysis phase and putting them relation to each other. The underlying problems will then become apparent .Within the scope of this graduation assignment, a range of different problems have been identified in the diagnosis process of AF. To have the biggest impact possible with this graduation project, it is important to determine the problem that is among most relevant and yet can be addressed with available technology. After this, a design direction will chosen, and the design brief is made based on this design direction.

5.1 IDENTIFYING THE MAIN CHALLENGES IN AF-DETECTION

From the analysis phase, it becomes apparent that there are three main challenges for the correct and useful diagnosis of AF.

1. Asymptomatic patient group
2. Identifying AF in the earlier stages of the disease
3. The significant variation in symptoms between different patients,

Together, these challenges make it difficult to identify AF based on an anamnesis alone.

The first challenge is the asymptomatic patient group. These cases of AF are often only captured by chance. This means that there is a large group of patients with AF without proper treatment to reduce the risk of a stroke.

Second is the patient group in an early stage of the disease. In this stage of AF, it is still difficult to capture an episode of AF with traditional sensing devices. Nevertheless,

This early stage represents the best time to treat AF and ensure that it doesn't become worse. Treatment in the first stage of the disease can also have the highest positive impact on the quality of life for the patient.

The third problem is that AF is hard to diagnose correctly due to the variety of symptoms and their often vague nature. Furthermore, symptoms of AF are common for a variety of diseases increasing the chance of misdiagnosis. Even if the GP suspects something, the symptoms cover such a wide range of diseases that sending a patient to the right specialist would be a challenge.

The difficulty to catch an AF episode at this early stage creates an additional dilemma for the GP: he either has to refer a patient to the cardiologist without a clear indication or send him/her home without a proper diagnosis. Sending patients to a cardiologist without a clear idea what the diagnosis could be lead to unnecessary cost, an overwhelming amount of patients at the cardiologist.

5.2 SETTING THE DESIGN DIRECTION

For the problems described above, there are multiple directions for potential solutions. For example: for the asymptomatic patients an extensive screening campaign can be set-up. However because of this projects's focus on tPPG technology and in an attempted to cover all of the problems, identified in the previous paragraph, with one solution, the decision is made that the creation of a support system for the detection of AF is the main design direction of this graduation assignment.

For these problems, most current diagnostic devices on the market are either (i) difficult to use and/or (ii) do not measure for a long enough period or (iii) are easy to use but the device can only perform spot measurements or achieve a low coverage, resulting in an inaccurate measurement.

Design statement:

"To provide a low threshold tool that supports the initial diagnosis of atrial fibrillation by the General Practitioner, while simultaneously collecting useful data for the further treatment and providing support for the patient."

Therefore, there is a need for a device that can measure over a longer period of time with a high coverage.

Because this graduation assignment is aimed at the AF diagnosis process, particular emphasis is placed on the role of the General Practitioner who has a crucial role in the early detection of AF.

In spite of the importance of the GP, there is a lack of products that focus on this part of the AF detection market. Of course, both the patient and the cardiologist will also be users of this device, so their needs will also have to be taken into account. This approach has the potential to provide the biggest impact possible with the device and the PPG technology. It leads to the design statement[statement above][Figure 69], on which every concept for this project will be based.

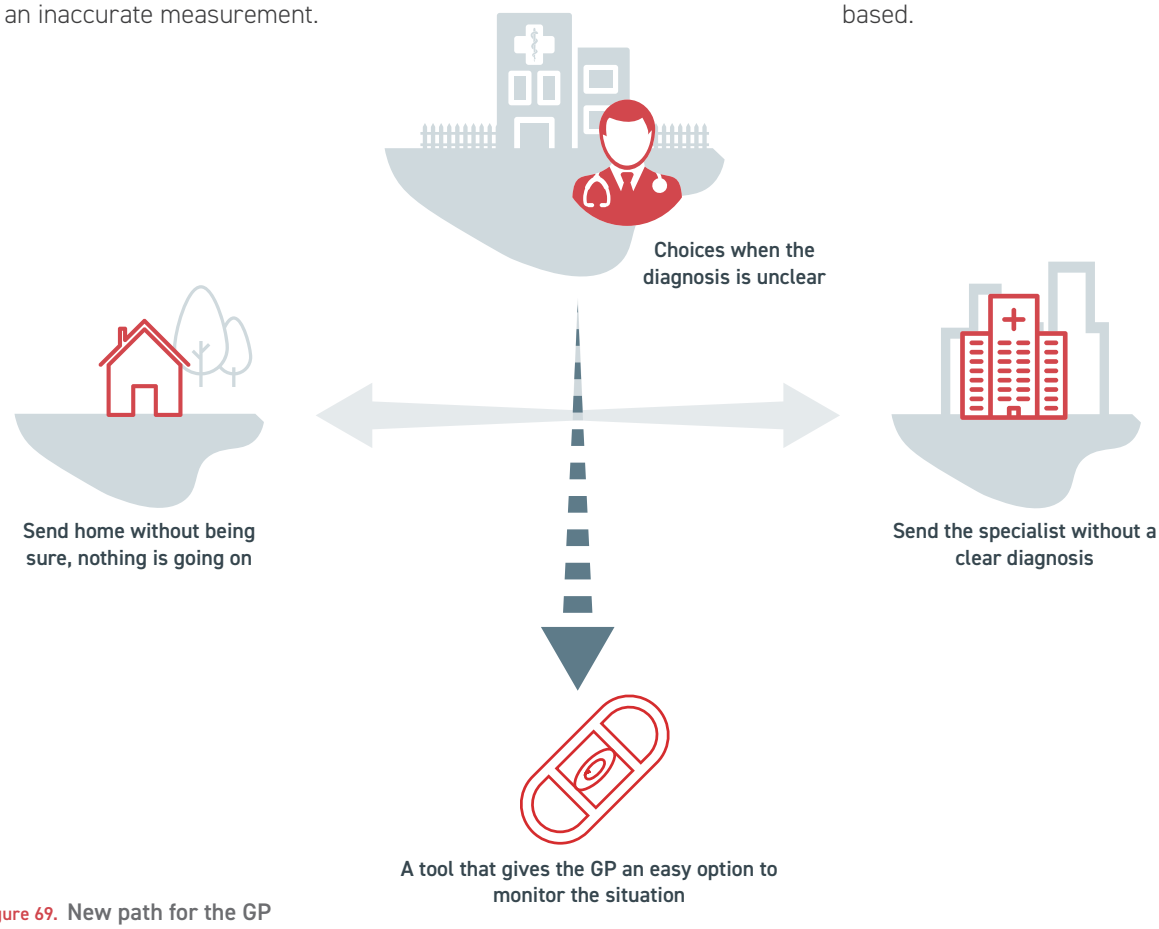


Figure 69. New path for the GP

6. - DESIGN BRIEF

Now that there is a clear direction for the design, there is a need for the formulated of a design brief. The design brief will form the basis of the concept, stating what is needed to create a successful concept. These requirements include hard and soft attributes, which are required to create a holistic product. These are needed to build ideas and concept that have merit and one which ideas and concepts can be evaluated.

6.1 ELEMENTS OF THE DESIGN BRIEF

In the design direction, three end-users have been identified, namely the GP, the patient and the cardiologist (for further treatment). All these users have a different set of needs. However, they are all of importance.

Furthermore, we need to take into account what it is exactly that we are trying see with the tool: the signal from the heart, which is necessary to diagnose AF.

We also need to take the current state of PPG technology into account to build a product that is viable. Without a clear signal, the tool will be useless. As discussed in the three chapter, technological development in general is a major factor for the clarity of the signal

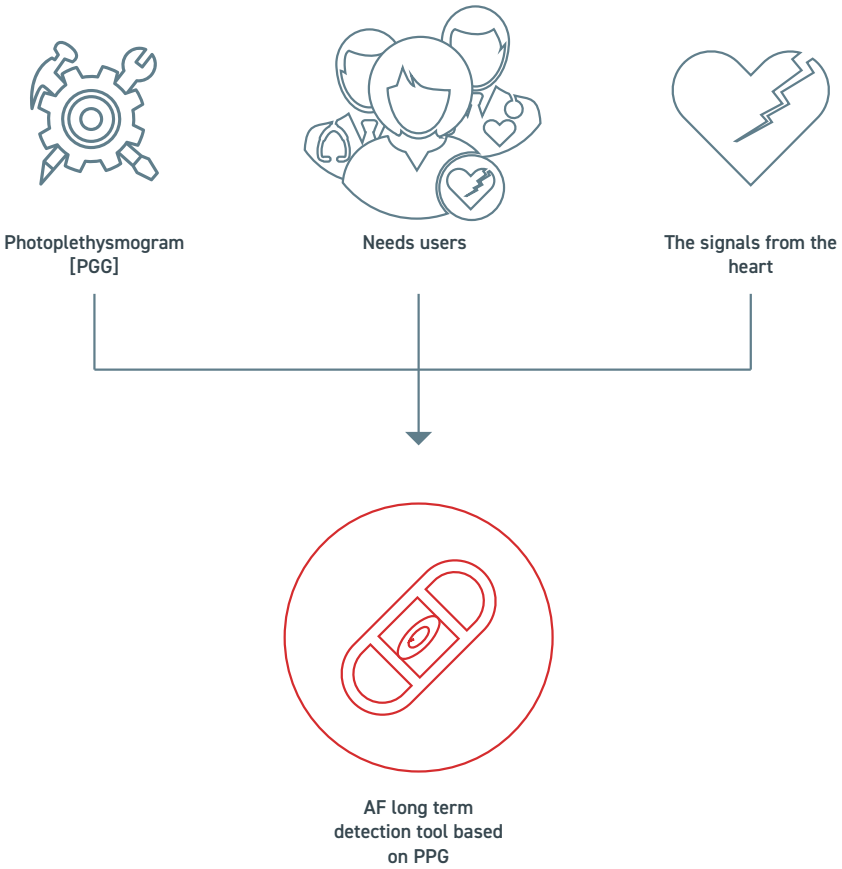
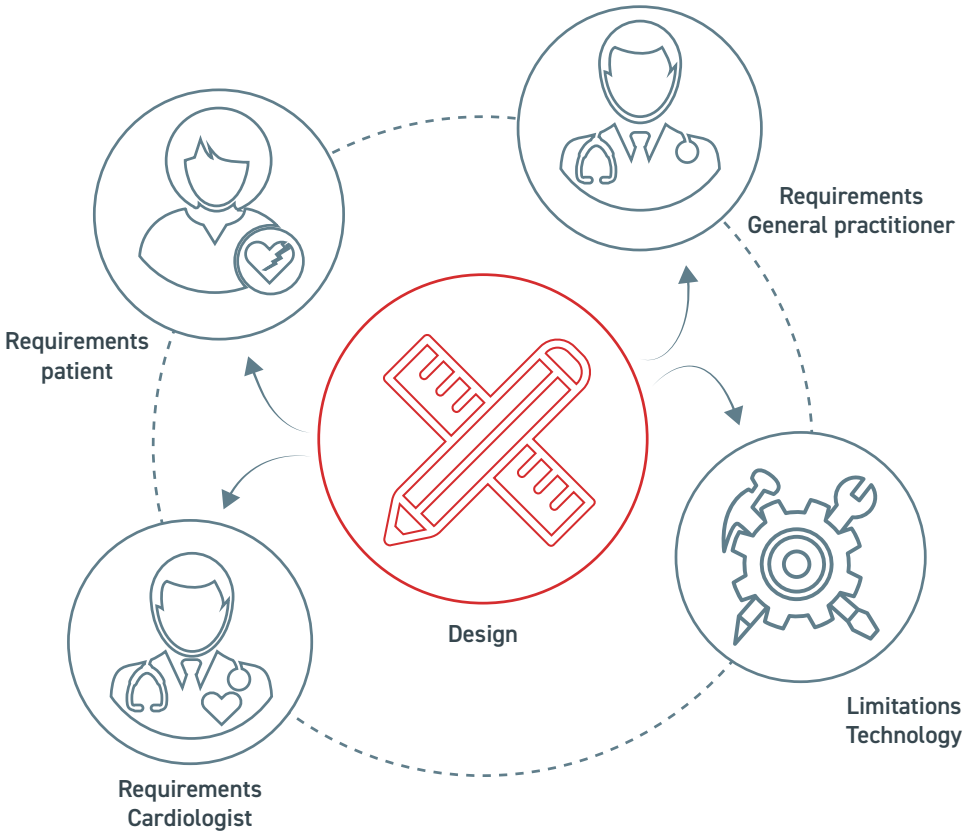


Figure 70. The three elements that make up the design

6.2 REQURIEMENTS

Each of the end-users has their own requirements for the product, however, the thechnology itself also presents limitations in the possibilities.. From these user needs and technological limitations, the design requirements are formulated. In this section we elaborate on the three most important requirements. Fig Figure 70shows the most important factors influencing the requirements. In Figure 71 [Next page] the requirements resulting from these factors are shown.



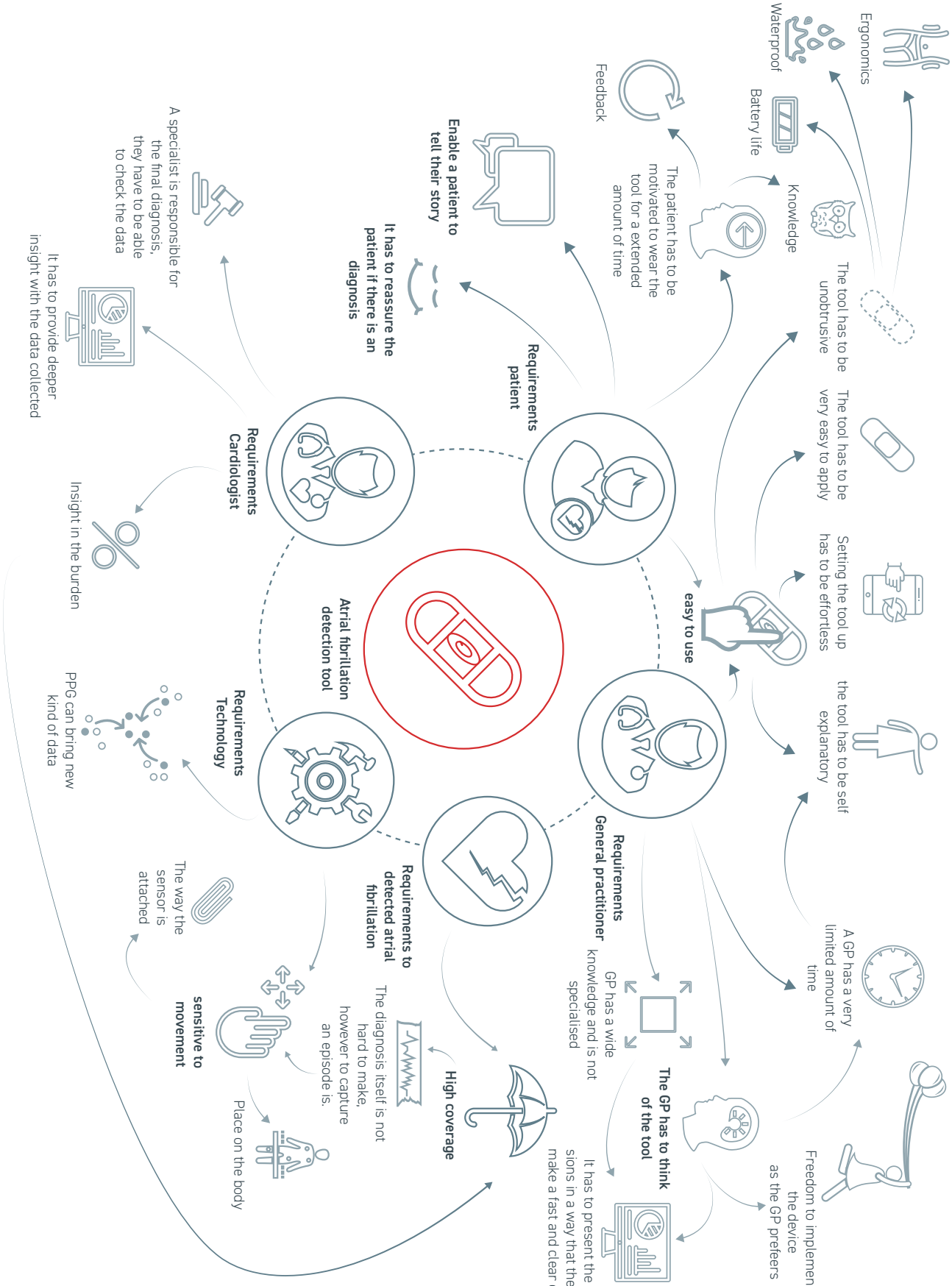


Figure 71. Requirements

6.2.1 High coverage

An overcoupling theme for all three user group, as well as the technology and the signal, is high coverage. Coverage is the amount of 'good' data the device can collect that is useful for AF detection; the amount coverage is dependent on a number of artefacts there are in the signal, which mainly comes from movement between the sensor and the skin. As discussed in previous chapters, AF is hard to diagnose in the early stages of the disease whilst treatment options are best and most extensive in the early stages.

A major issue with coverage is independent movement of the device in relation to the patients body during the measurements. In order to improve the coverage with a PPG sensor, less movement is therfore required. This can be achieved through three approaches: improved body placement of the device, sturdier attatchment of the device to the body or by active action(or rather inaction) from the user[Figure 72].

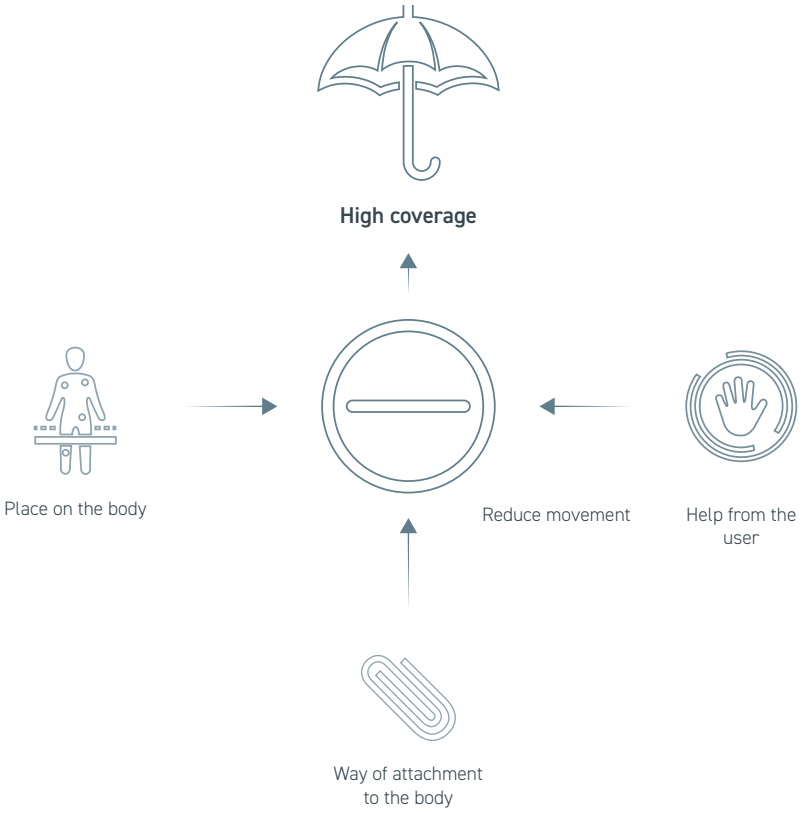


Figure 72. Focus for design

Figure 73. **Look and feel**

6.2.2 Look & feel

The Feel of any product is essential. In order for patients to be willing to wear the device, it must not feel like a burden. A major part of this comes from the device not making them feel like a patient. If it does, it might becomes the case that patients refuse to wear the device. The look of the device significantly contributes to that. Making that achieving a desirale feel requires a subtle design look. However, the device remains a medical device and is therefore required ,to be and feel clean; smooth lines will contribute to this. These looks and feelings are symbolised in a college in Figure 73

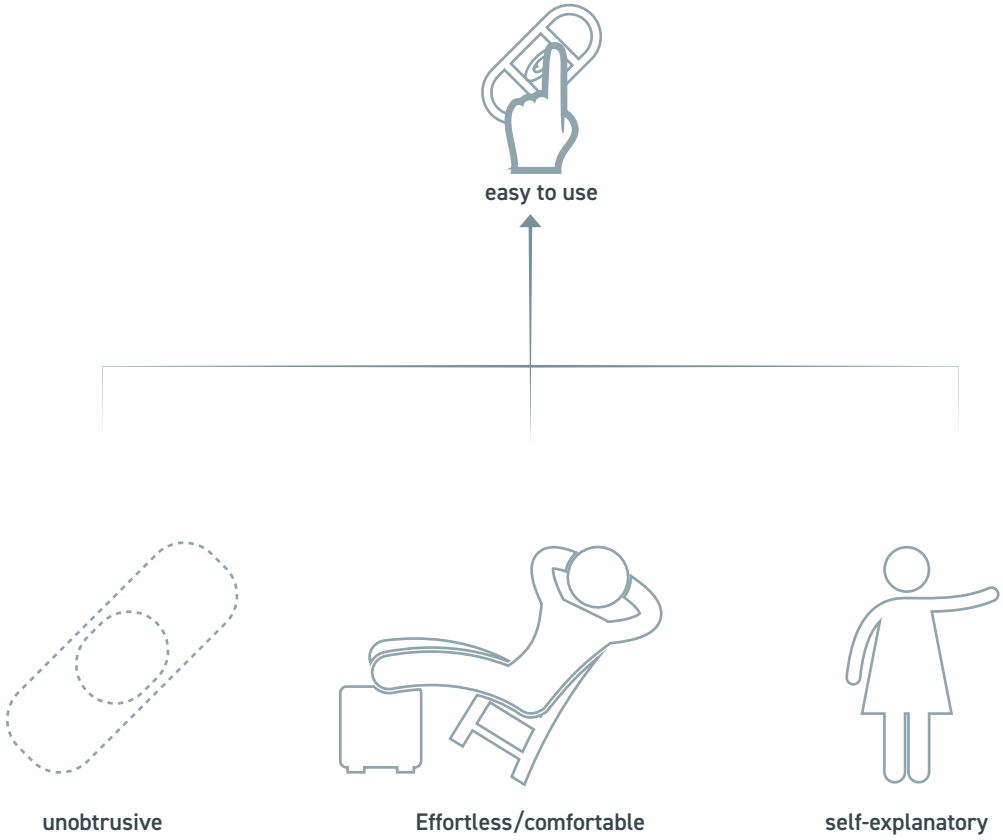


Figure 74. Elements of ease of use

6.2.3 Ease of Use

Ease of use consists out of three elements[Figure 74]; unobtrusiveness, comfort and self-explanatory.

First of all, the device must not be obtrusive; the device has to be as compact as possible and be placed in a location where it does not irritate the user.

Furthermore, the device must be comfotable and effortless to use. This means that it does not require much thought. In essence, it has the right feeling, the patient just wears it, and it works.

Finally, the device itself has to be so straightforward. The shape and design must make its use self-explanatory. This will reduce the time required to explain the application to the patient, which is important for GPs as they only have limited time for each consultation. In line with this, the device also has to be simple. This will further reduce the time required to explain the use and moreover, it will also help to avoid user mistakes.

7. PHILIPS AFI

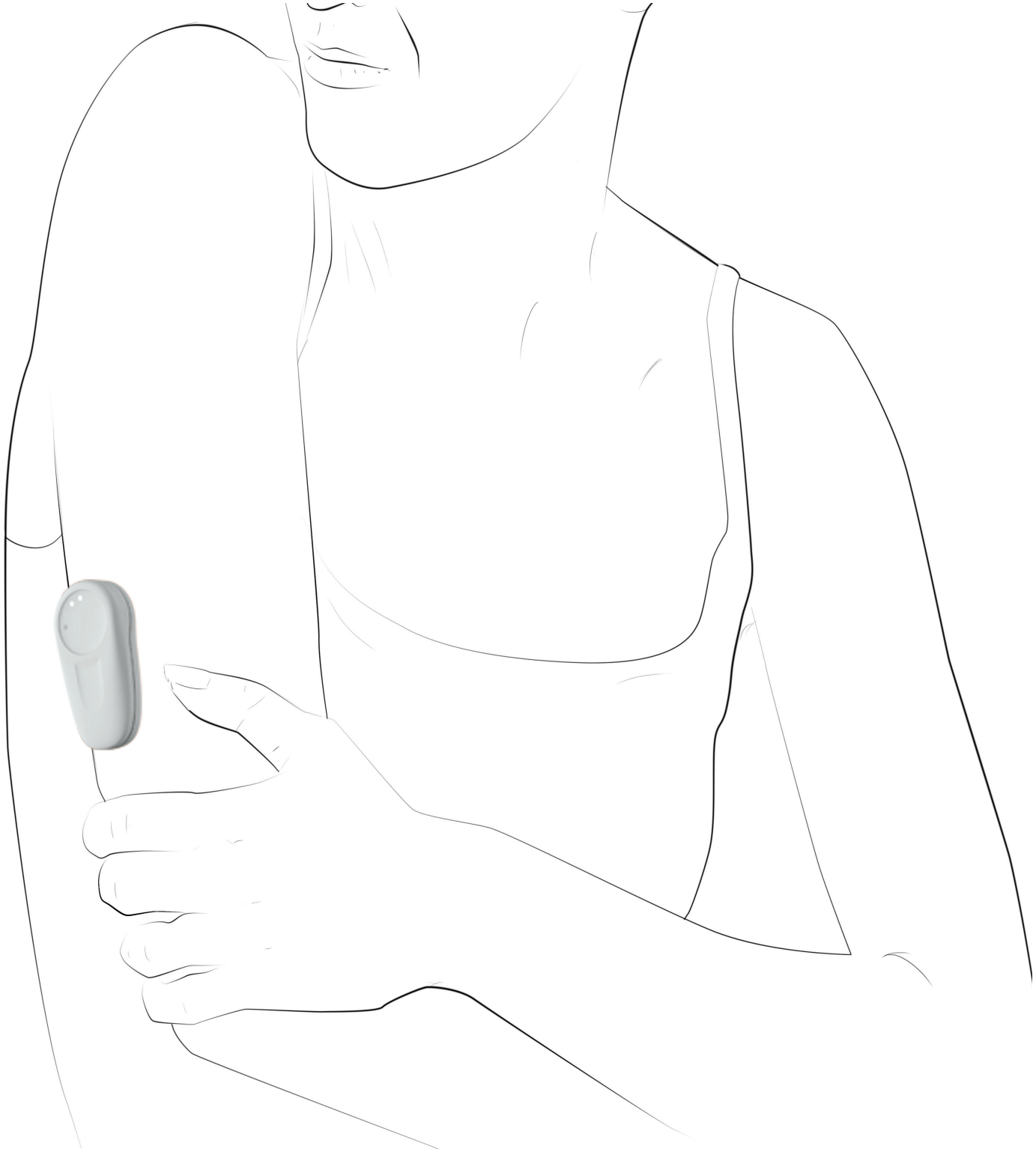


Figure 75. User using the AFi

Figure 76. AFi upclose

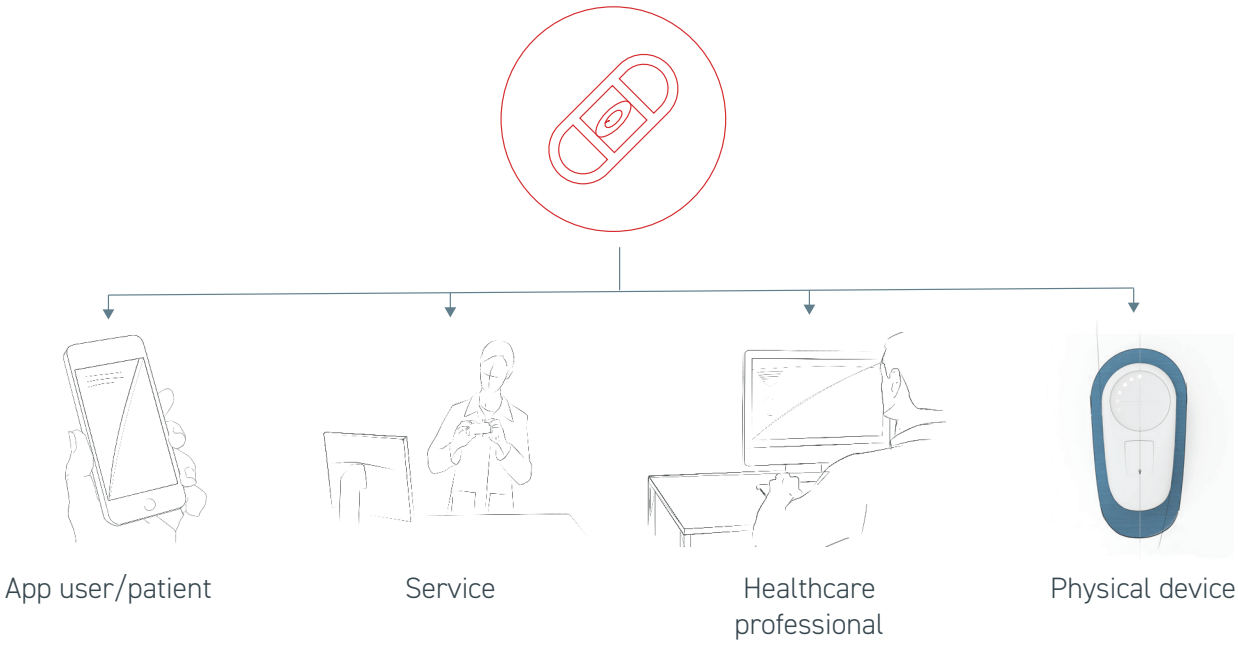


Figure 80. **Different parts of AFi**

7.1 PHILIPS AFI

Philips Afi is a continuous unobtrusive monitoring tool for AF. It uses PPG to detect arrhythmias and warns the users in case these are indeed detected. From that point forwawrd Phillips Afi starts measuring the burden of AF.

To increase the detection coverage, Afi will be placed on the upper arm with a medical grade double sided adhesive sticker. Furthermore, it will ask the user to be still for a short period of time whenever it is in doubt of a positive detection due to movement artefacts.

Afi is connected within a system[-Figure 77], which includes the Afi patient app and a system forthe healthcare professional. The patient app will provide the patient with feedback on the measurements. The feedback can be simple, such as heart rate and heart rate variability. However, it also possible to let the user know immediately if AF detected and what the burden is. All recorded data is sent to the system for the healthcare professional; this system is built for the GP and the Cardiologist. Both their needs are taken into account by creating using multiple levels of use, essentially creating depth.

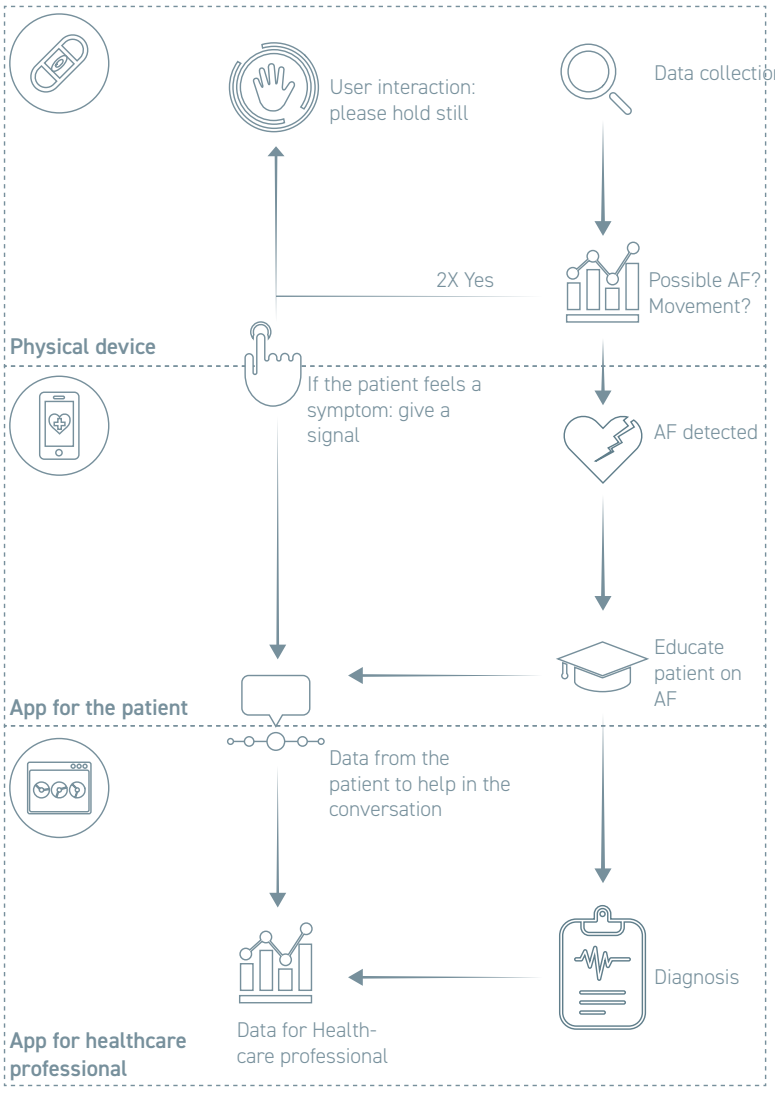


Figure 77. **System of AFi**

7.2 IMPACT ON THE DIAGNOSIS PROCESS

7.2.1 First GP Visit

With the Philips Afi, the GP has a new option in his tools to reach a diagnosis. Even when someone comes in with a story that could indicate an arrhythmia, but is not experiencing an episode at that specific moment. With Af there is now the opportunity to monitor a patient for arrhythmia, whilst requiring minimal time investment from from the GP.

Afi easy to use, the GP or even their assistants can explain[Figure 78] the basics of the system whilst the app that comes with Afi continues to support the patient.

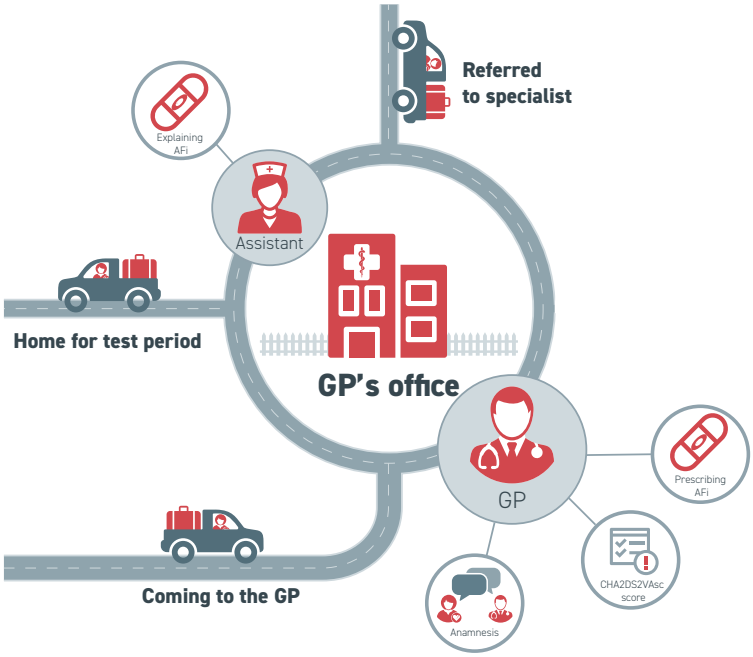


Figure 79. Changes at home

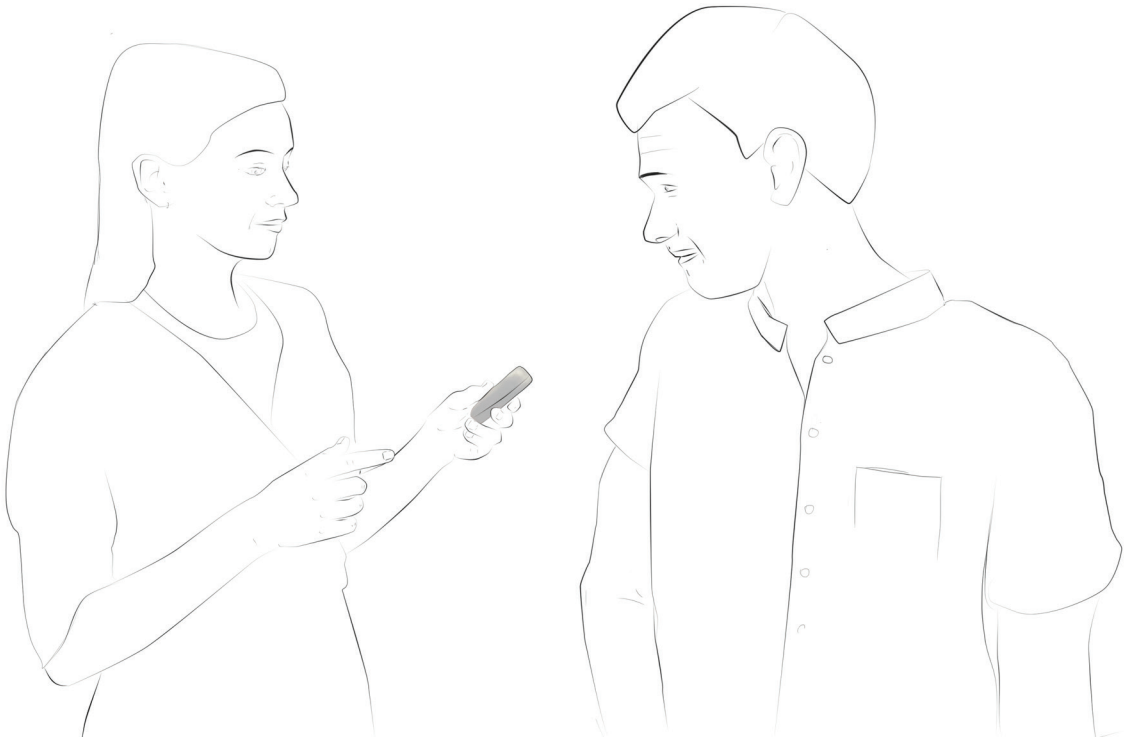


Figure 78. Assistant explaining the basics of AFi

7.2.2 Afi at Home

Afi scans for AF, whilst not being obstrusive. It might happen that the systems algorithms detect AF, however, due to movement artefacts it is not able to exclude the possibility of a false positive. In this case, Afi will ask the user to keep their arm still for a period of 30 seconds[Figure 81]. This will be done by an app notification and a haptic (small vibrations) signal from the device itself. Furthermore, Afi will reassure the patient on what they experience. As it happens from time to time that a patient thinks they are experiencing an episode, eventhough this is not the case.

When an AF episode is indeed detected, the app[Figure 83] will advice to schedual an appointment with the GP. The app will also provide information on AF. It is of importance that the app reassures the patient of the fact that AF is a non-life-threatening condition and there is no need

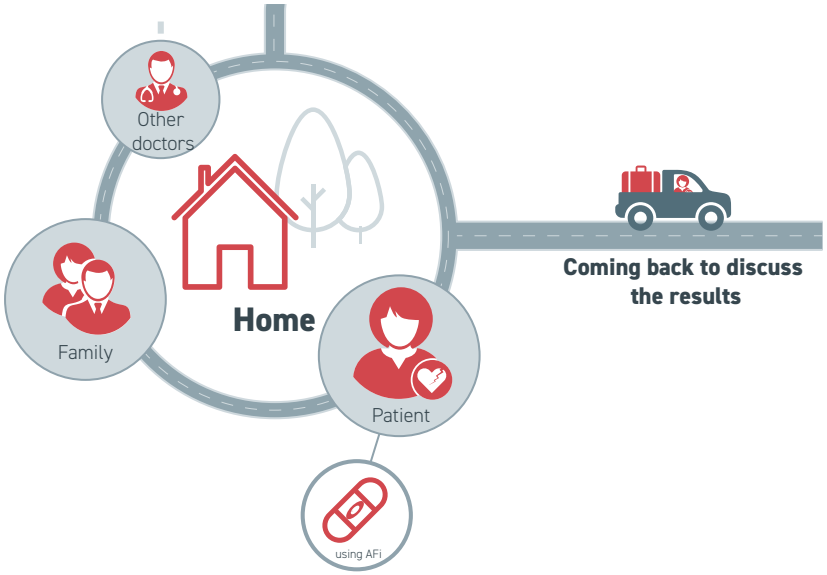


Figure 82. Changes at home

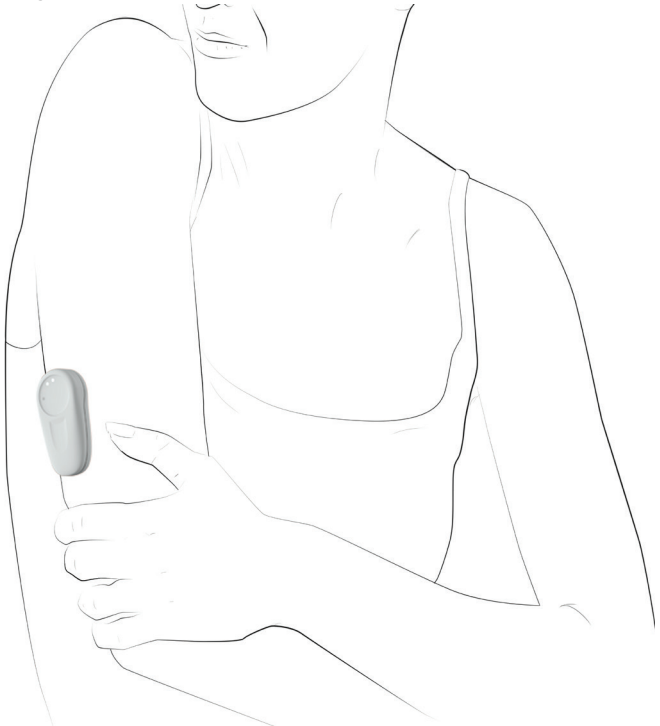


Figure 81. Patient wearing device and holding still

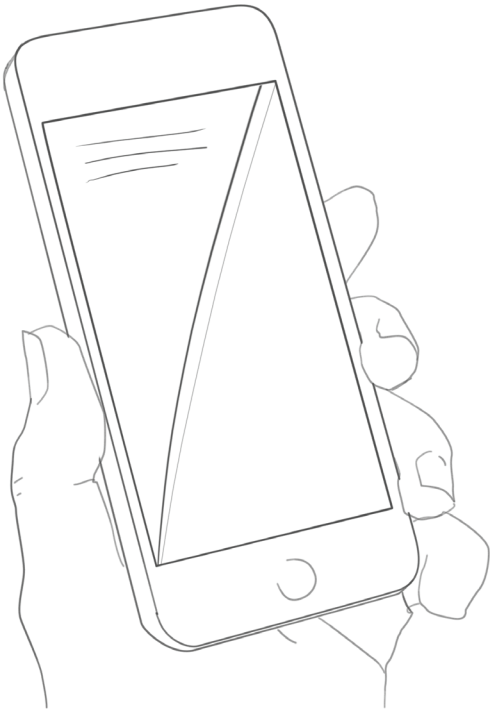


Figure 83. app

7.2.3 Second visit to the GP

During the second visit to the GP's office, the patient and the GP will discuss the results; this will enable a different form of interaction because the patient collected their data with a medically approved system. It is expeccted that this will give a different feeling. Rather than the patient only receiving bad news from the GP, the patient will now be able to talk about AF in a more informed manner[Figure 84]. Eventually, the GP will refer the patient to a cardiologist.

Figure 85. Changes at the GP

Figure 84. GP and patient discussing the result

7.2.4 AFi at the Cardiologist

The patient will be asked to keep wearing Afi untill the appointment with the cardiologist. This will enable the system to provide the GP with more information on the burden and the state of progression of AF, Giving the cardiologist a better understanding of the situation and allowing them to provide the most suitable treatment path[Figure 86].

Ideally, the Afi will replace the current standard of the Holter test. Due to the different information an 12-lead ECG provides, it is not expected that the Afi will replace these tests. However, 12-lead ECGs are significantly less inconvenient when compared to a Holter test, due to the duration of the test.

Figure 87. At the hospital

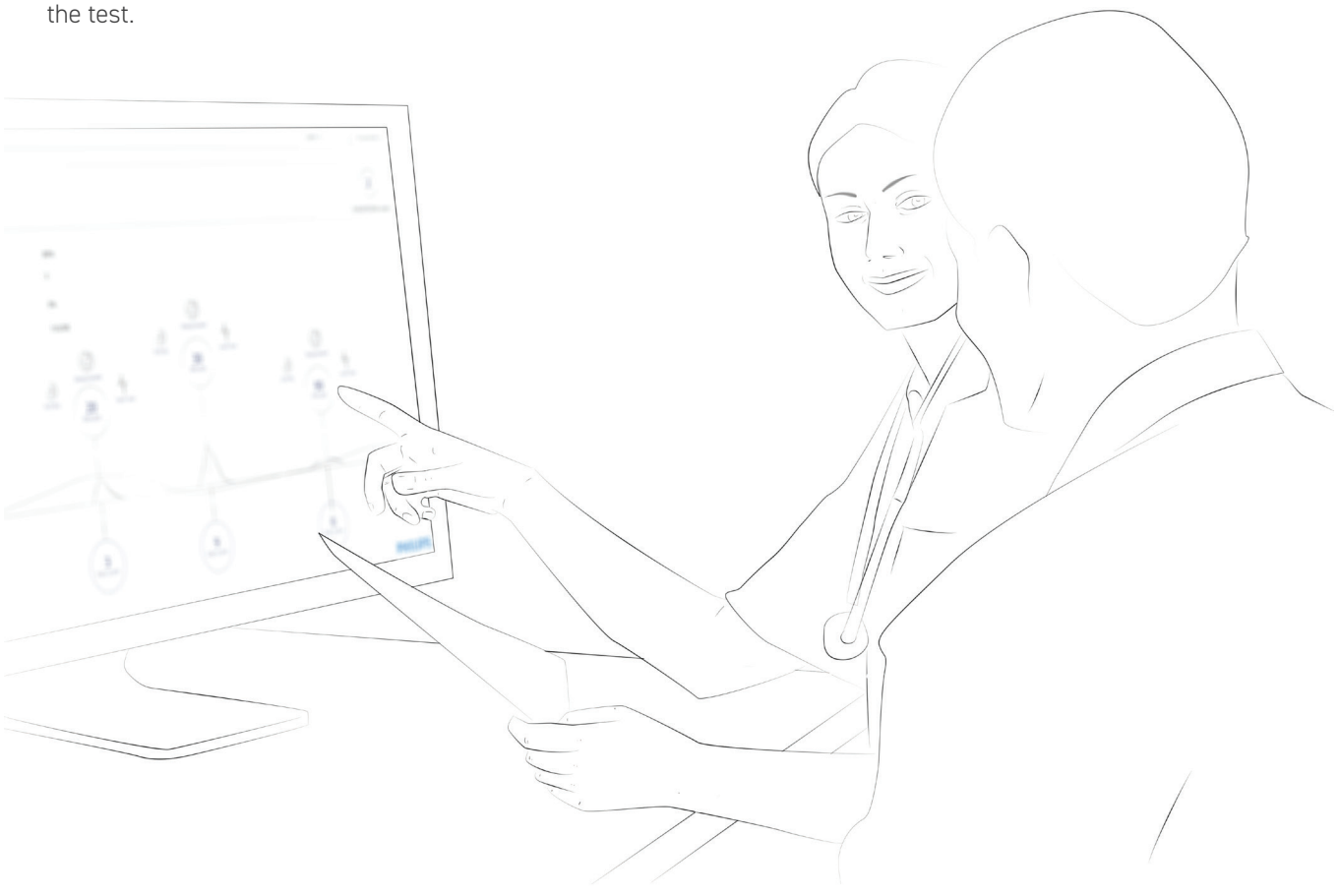


Figure 86. Cardiologists discussing the new insights

8. - PHYSICAL DEVICE ELABORATION

The main objective of this chapter is to expand on the physical design of Afi. In order to make the product usable, many minor, yet important, decisions have to be made.

Here we will elaborate on the design, user interaction with the physical device, attachment Afi to the user's body and the battery.

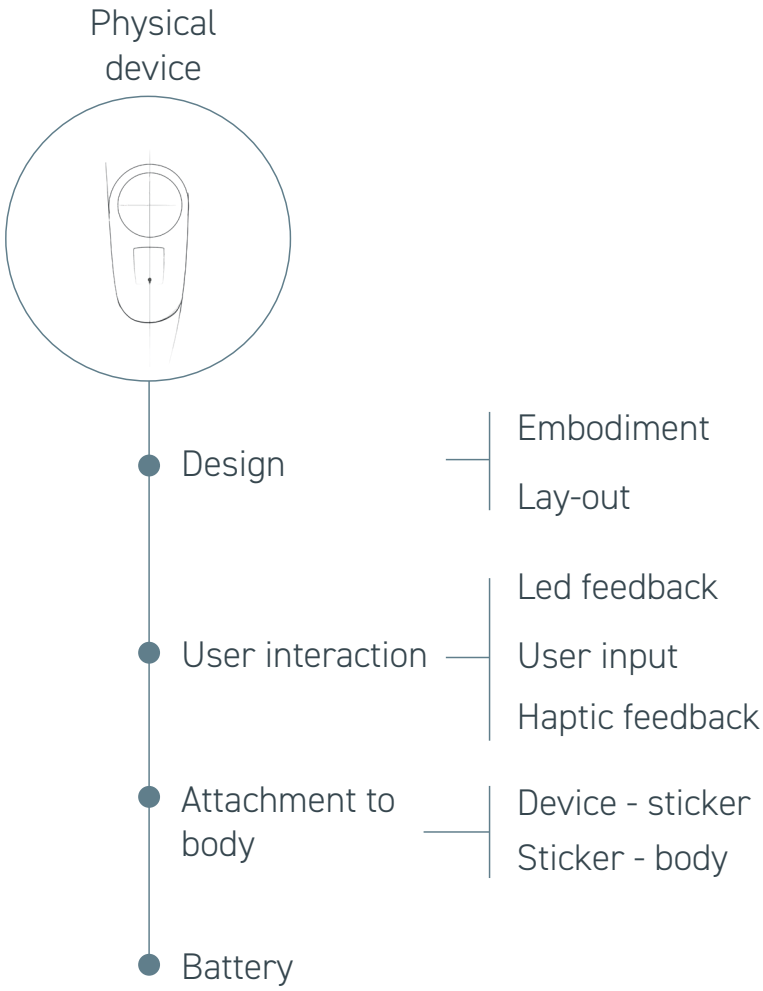


Figure 88. different parts of the elaboration of the physical device

8.1 LAYOUT

A sandwich construction is used to fit all the components in the right place. While almost all the elements are on the main PCB, the PPG sensor and LEDs need to be in a particular location. One on the bottom, the other on top.

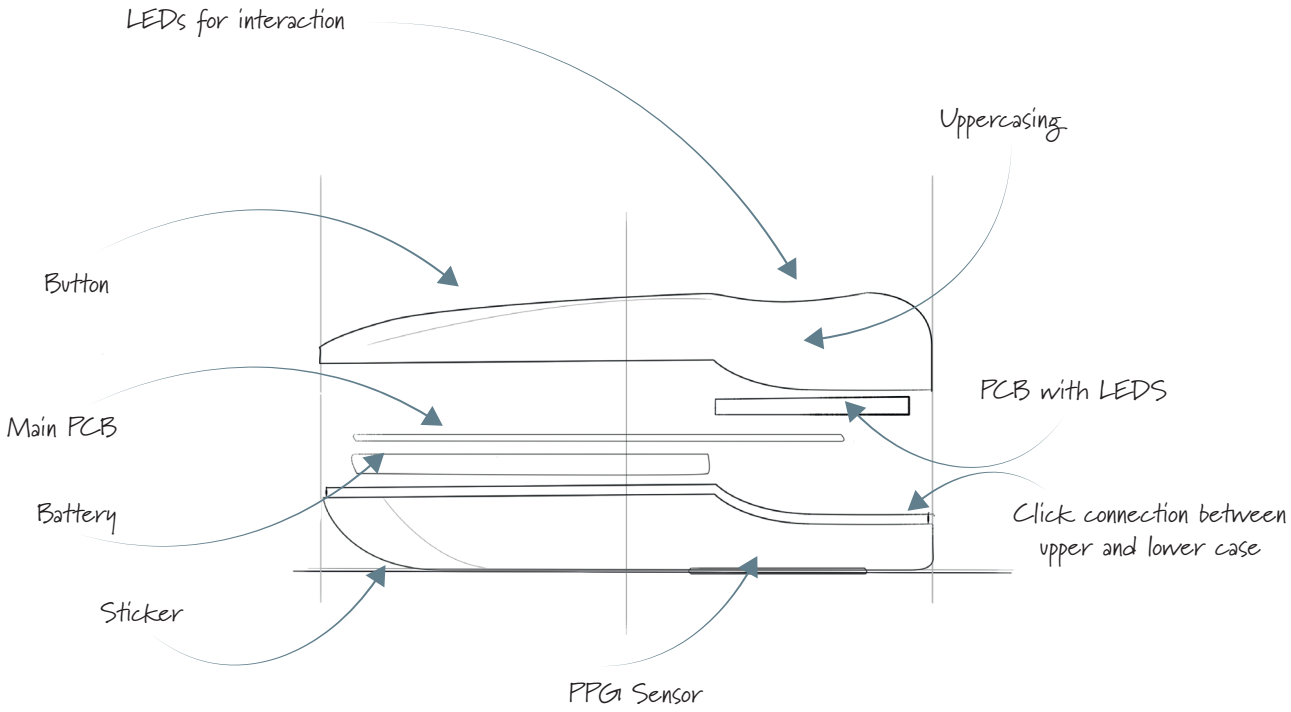


Figure 89. layout

8.2 EXPLODED VIEW

8.1.1 Lip - groove

Afi is meant to be continously worn over an extended period of time. Therefore, it has to be waterproof up to IP67, meaning dustproof and water-proof up to a meter submersion for 30 minutes. A small rubber silicone band between the lip and the groove will ensure this.

8.1.2 Flat surface to body

The adhesive sticker is attatched to the bottom of Afi. To ensure the best surface connection this area must be flat. Furthermore, the finish of the base has to be slightly rougher in order to provide a larger surface area. The rougher finish will enable a better adhesive connection

8.1.3 PPG sensor placement

The PPG sensor pertrudes slightly from the casing. This will push the PPG sensor slightly into the skin. The user will not notice this difference, however, it will ensure a better signal.

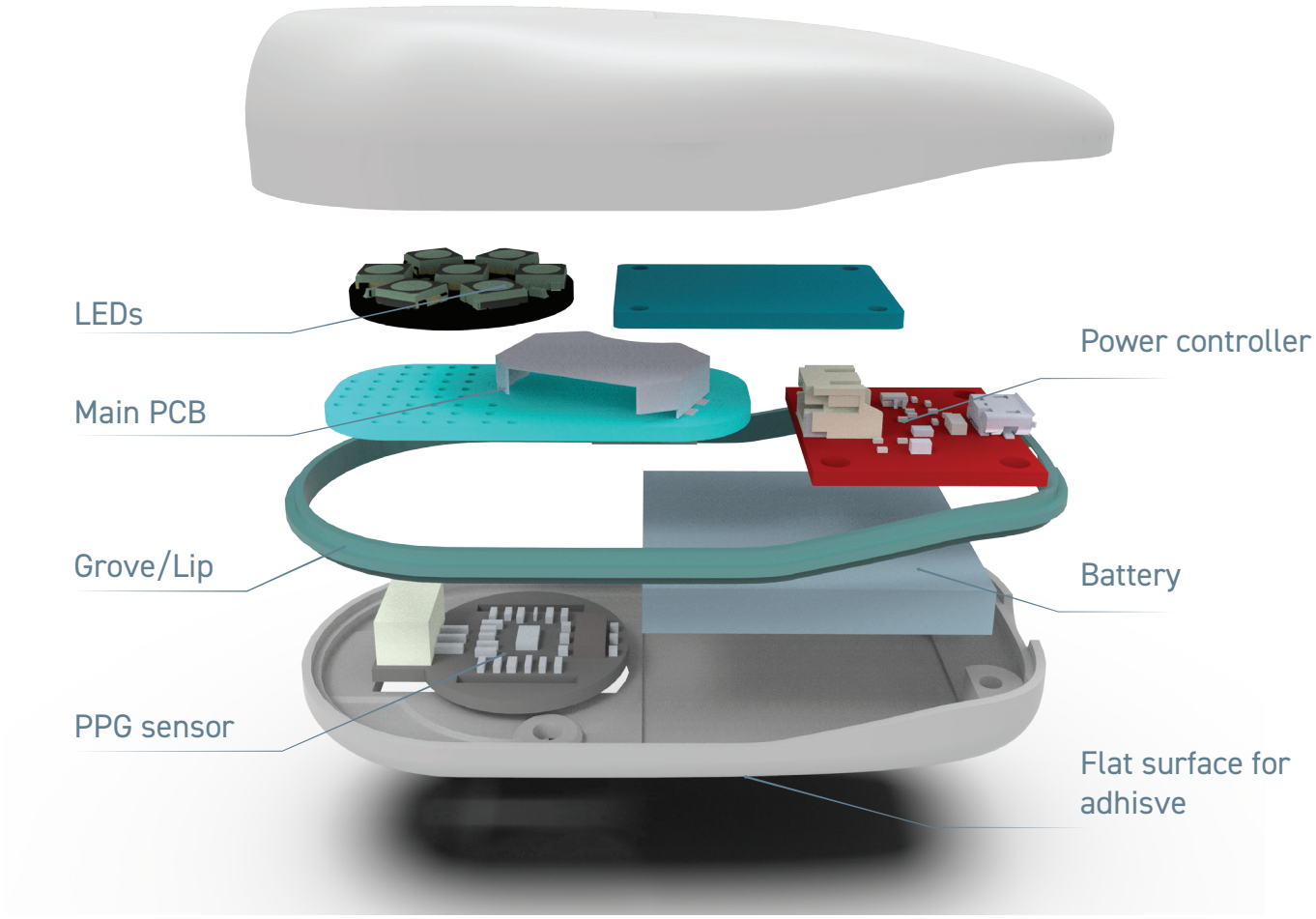


Figure 90. Exploded view

8.3 INPUT AND FEEDBACK

8.3.1 Graphical feedback

The systems must have a method to signal the time a patient needs to be still when required. In Afi this is achieved in a graphical manner[-Figure 91]. Sub-surface LEDs signal a circular pattern. Sub-surface LEDs are chosen since they keeps the outside sleek. This is in line with the design requirements and the need for an IP67 rating.

Figure 91. frontview graphical feedback

8.3.2 Haptic feed back

Although the LEDs are the primary method of communicating with the patient, the device can also be used underneath clothing. This means that the LEDs will not always be visible to the user. Therefore haptic feedback is used as the second method of communication. Haptic feedback is done by a small vibration motor [Figure 92] that gives small but noticeable vibrations, similar to any modern smartphone. Different vibration patterns will convey different messages from Afi.

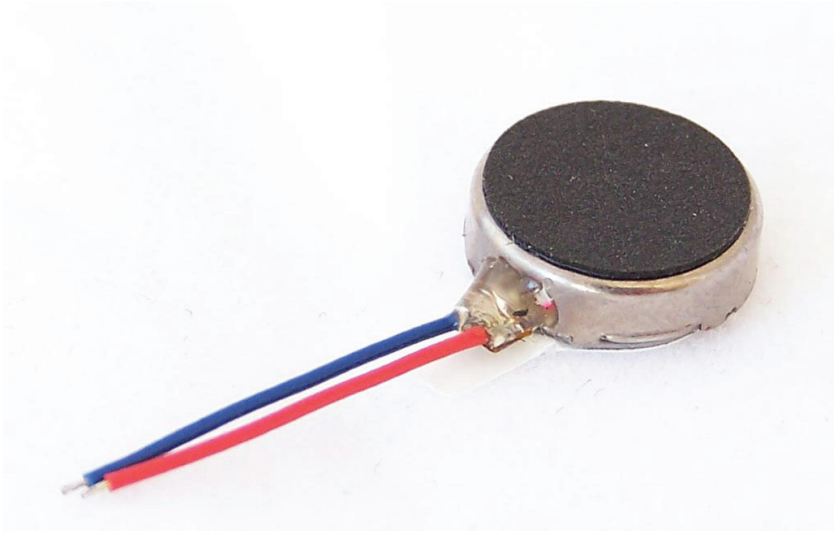


Figure 92. Vibration motor

8.3.3 User input

The user can also let Afi know when they feel an AF episode coming up. This will trigger a 30-second timer. To do this, the user has to be able to give an input to Afi. For this a button is required. However, the design needs a sleek, and clean look and the button has to be able to be used underneath a layer of clothing. A physical button will therefore not suffice. This problem was solved by the utilisation of a captive touch button [Figure 93]. A captive touch button only requires the user to put a finger in the area of the captive touch, and the button is triggered.

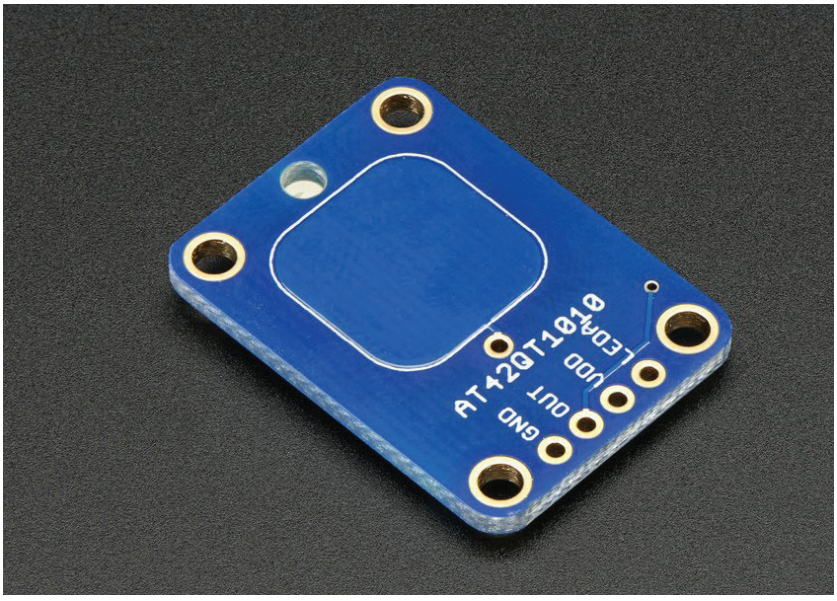


Figure 93. Adafruit captive button

8.4 ATTACHMENT

Afi is designed to be atached to the body [arm] of the user by the use of a double-sided adhesive sticker. Afi is used continously for up to six weeks. However, no adhesive is currently available that will hold over such an extensive period of time. Therefore, the sticker needs to be changed several times during the measuring period. The period a single adhesive sticker lastst greatly depends on the skin and lifestyle of the user. While some people have a skin that will allow the sticker to sit for long periods, others might only allow it to remain attached for a day or two.

The two sides of the double-sided adhesive sticker[Figure 94] are different; one is a medical grade adhesive that will prevent irritation and sticks best to skin, the other side is specially made for connecting to plastics and allow it to remove after use, this side will attach to Afi

.

To make it easier for people to change stickers both sides have an unique label that will also help with the pealing of the protective layers.

Figure 94. Stickers with lips

8.5 BATTERY

Afi has to be used continuously, therefore there is no time to charge Afi. Batteries provide a solution for this. The batteries will be positioned in their insert case and can be interchanged and charged separately from Afi. Afi will use Lipo batteries, these have a relatively high energy density. This makes for a good trade-off between the time of use Afi whilst not compromising the weight of the device too much.

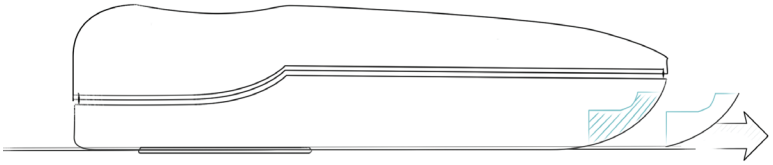


Figure 96. Battery slide drawing

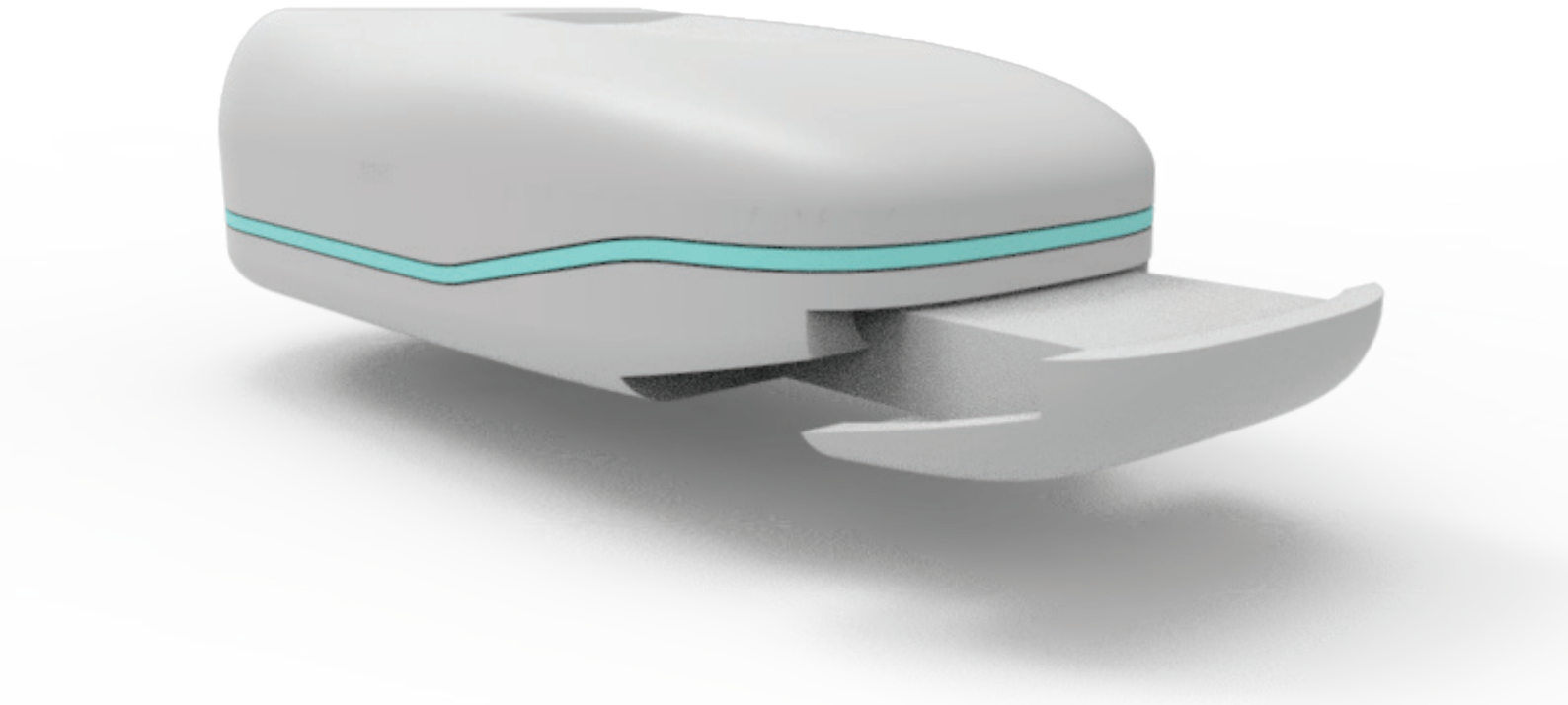
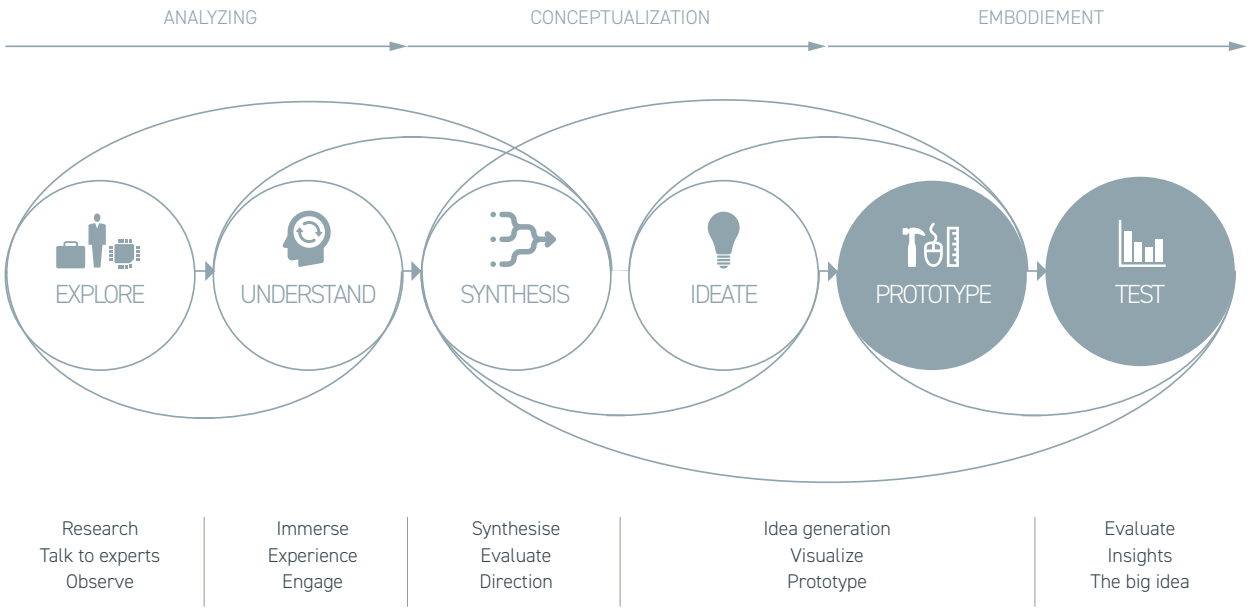


Figure 95. Battery slide

PART III - EMBODIMENT

In the conceptualization phase, Afi was born, now it is time to make Afireal in the form of a prototype and test it. This phase called the embodiment. First, an objective is set to define what is to be achieved with the prototype; then a prototype plan is made and executed. Building a prototype is very much an iterative process and it provides a good opportunity for evaluation of the initial design and further learning . This process enables the concept of Afi to grow into a real product.



9. - PROTOTYPE

As mentioned before, prototyping is an iterative process requiring many learning cycles of learning to get it right. It starts with a simple 3D CAD model to learn about the shape and to improve this. 3D printing on a simple printer was used extensively to support these iterations and to gradually improve the design, gaining more insight with every cycle. Finally, the simple 3D printer was replaced by a better model printer to achieve a higher level of detail in the models. Then the electronics were added to make the prototype function. Simulation code it was written to create a fully functional prototype.

9.1 GOAL OF THE PROTOTYPE AND PROTOTYPE PLAN

The goal of the prototype of AFi is showing the working principle of AFi, the possibility to detect PPG data from the arm which could which is used for the detection algorithm of AF. The second goal of this is the prototype is used to evaluate the concept of AFi with healthcare professionals. Thirdly the prototype will be shown at the Mind the step exposition in the 2017 Dutch design week.

The prototype will exist out two parts[Figure 97], the physical device and the digital platform. Between them will be a connection which enables the digital platform to work with the real data from the physical prototype. This part is outsourced, due to the technical expertise which is needed.

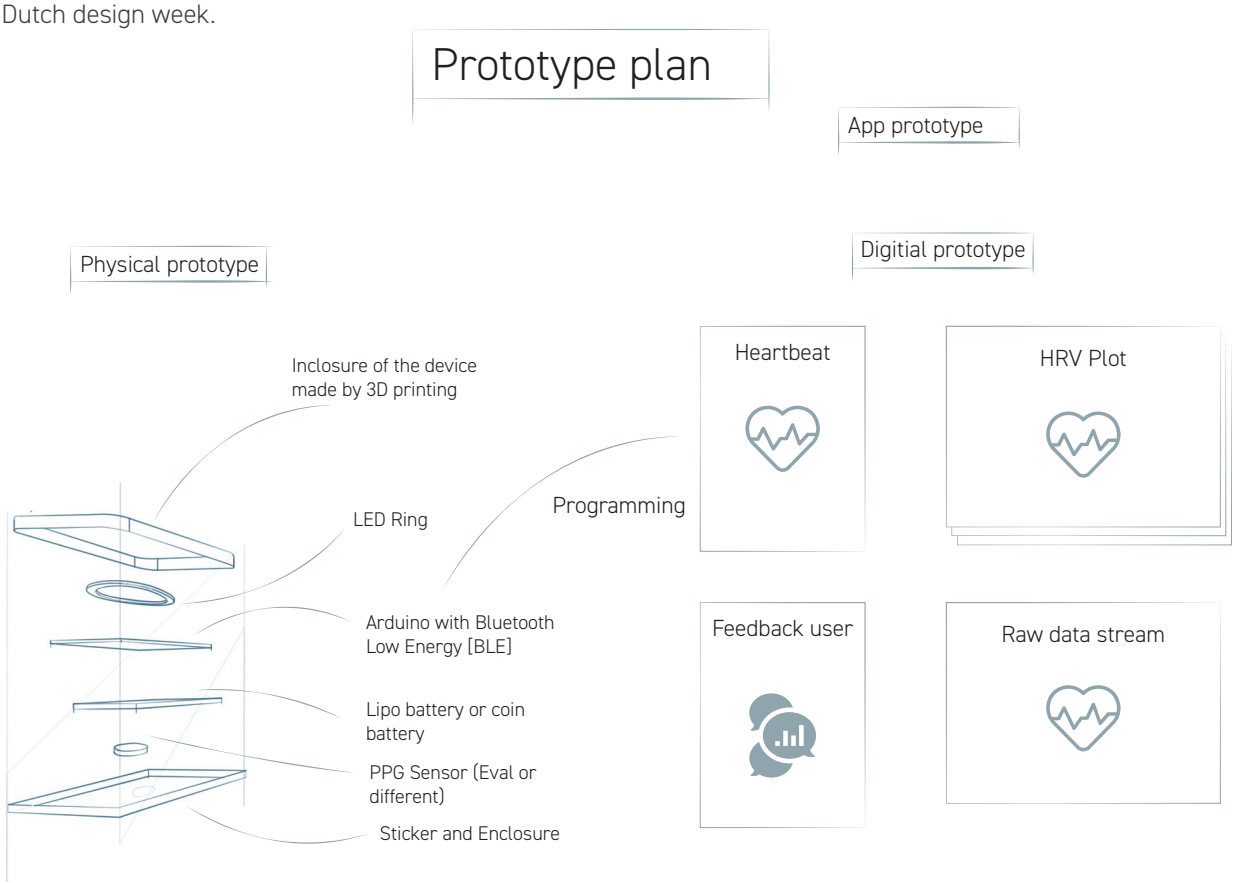


Figure 97. Collection of first 3D prints of AFi

9.2 FIRST MODELS

In Figure 99 the first 3D models are shown; they are shown chronological order, from the earliest models on the left to the later ones on the right.
The first models were used to establish the final shape, the later ones to test:

- the working principles of holding the PPG sensor,
- Different ways to attach Afi to the body,
- Connections between the various components of Afi and
- Comfort while wearing Afi.

These models were made using an Ultimaker 2+, which uses fused deposited modeling [FDM], a technique which uses layers of extruded plastic [PLA] to form the model.

Figure 98. **Very first shapes**

Figure 99. **All the different FDM prototypes**

9.3 BUILDING THE PROTOTYPE

9.3.1 The final shape

For the prototype, some of the electronics needed to make Afi work, had to be off the shelf parts . than the parts that would be used in the real product, when most of the electronics would be fitted onto a single printed circuit board (PCB). Consequently, the prototype's body size had to increase.

Figure 100. AFi just taken out of the Formlab 2

9.3.2 Electronics

To realise a working prototype there is a need for a combination of the right electronic parts and coding.

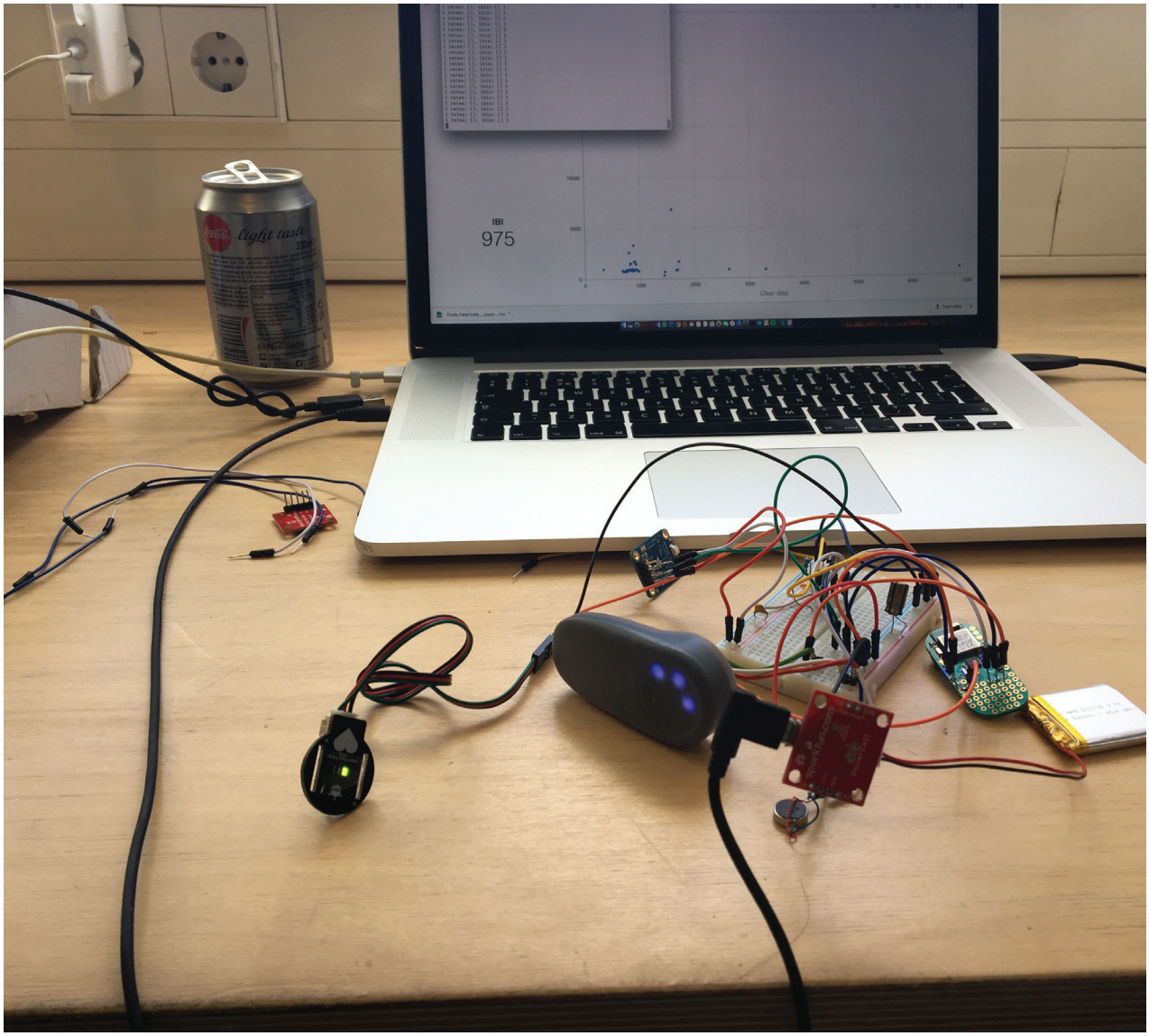


Figure 101. Prototype board with all the components.

9.3.4 Arduino

An Arduino is a prototype platform for electronics. Usually, all the electronic components are located on a PCB, however, to manufacture these cost a lot in production and design. To create a real PCB is not within the budget and time of this project. Therefore the Arduino platform is used to build these first prototypes. There are several different types of Arduino on the market. The first testing of the combined electronics was done with an Arduino Uno. However, this model is considered to be too large for the Afi, even as a prototype. Therefore, in the prototype, the smallest option was used, the Lightblue Bean [Figure 102]. This model Arduino has the advantage of built-in Bluetooth and power supply.

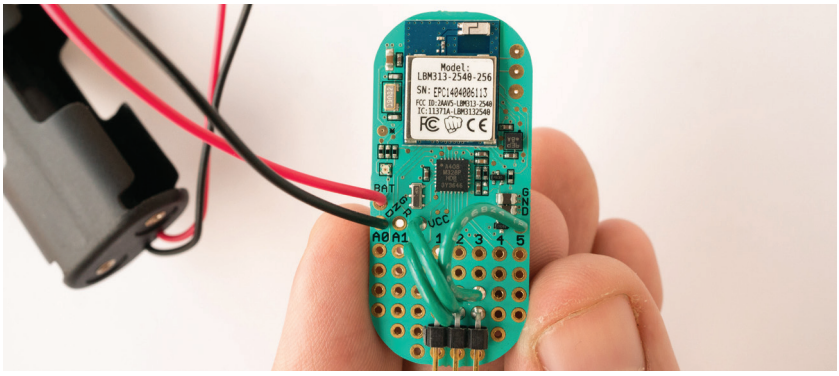


Figure 102. **Lightblue Bean**

9.3.5 PPG Sensor

The most important part of Afi is the PPG sensor. Therefore, a lot of different sensor models were tested. The Philips PPG sensor has the best performance, however, this model is difficult to program with an Arduino. Therefore, the DFrobot PPG sensor [Figure 103] was selected for the prototype.

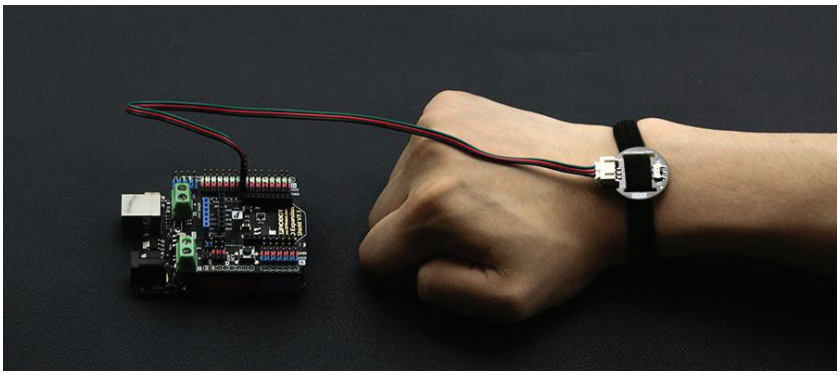


Figure 103. **DFrobot heart rate sensor with a arduino**

9.3.6 Power source with controller

During testing, it was found that the power supply from the Lightblue Bean was not robust enough to power all the components. Therefore, a Lipo battery and a controller were added to the prototype. The Lipo battery [Figure 105] was chosen on account of its relatively small size while still providing enough battery capacity. The controller [Figure 104] ensures delivery of a stable voltage to the components and creates the possibility to charge the battery without taking it out of Afi.

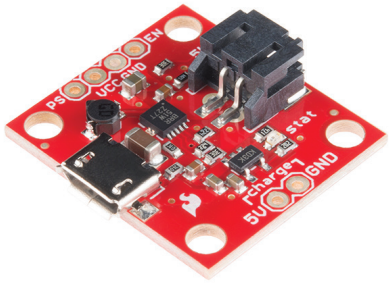


Figure 104. **Powercell from sparkfun**

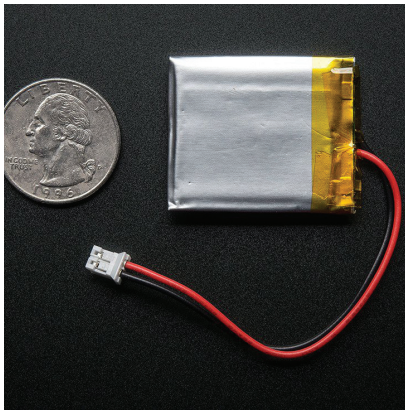


Figure 105. **500mAh Lipo battery**

9.3.7 Captive button

A captive button, which is needed to interact with Afi, is used to create a button that is flush with the body of Afi. These buttons really on proximity to turn off or on and therefore do not need a physical moving button within the housing. The captive button from Adafruit [Figure 107] because it does not need extra electronics to work properly, contrary to many of the alternatives.

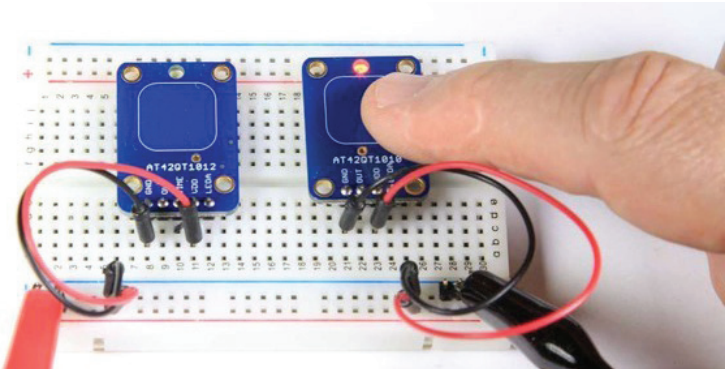


Figure 107. Adafruit Capacitive Touch Sensor Breakouts

9.3.8LEDs

The Jewel Neopixel [Figure 108 from Adafruit was selected for its circular shape, which fits Afi's design perfectly, its ability to function without added electronics and the possibility to individually program the pixels.

Figure 108. Neopixel Jewel

9.3.9 Vibration motor

The vibration motor is a standard small vibration motor, however, to control it better, a small vibration motor controller [haptic controller] [Figure 106] has been added. The reason for this is to decrease the amount of soldering and wires needed.

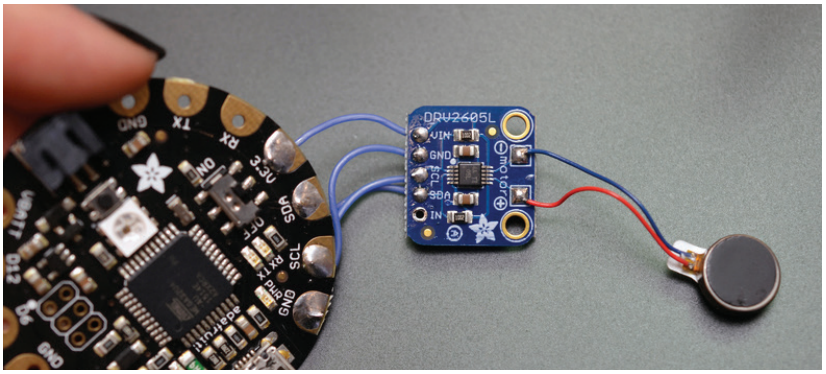
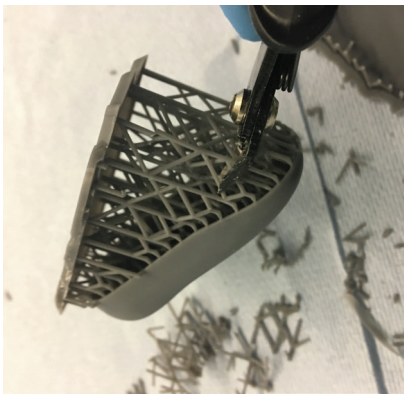


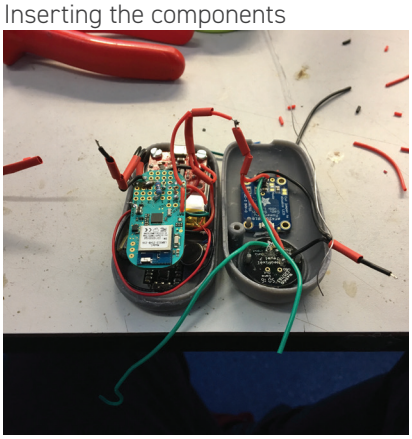
Figure 106. On the right: vibration motor, in the middle Haptic controller, left arduino

9.3.10 Assembling the prototype

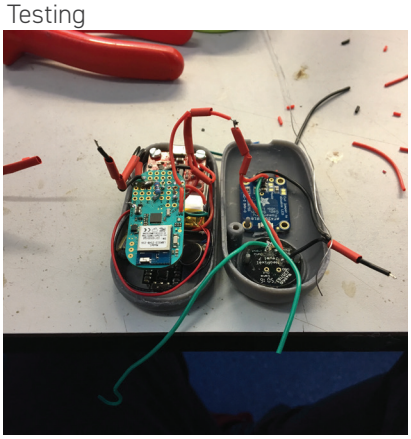
Cleaning of the 3D prints



Inserting the components

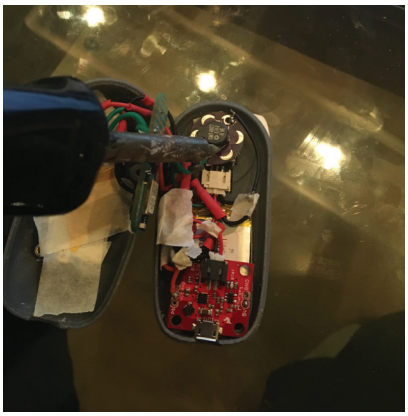


Testing

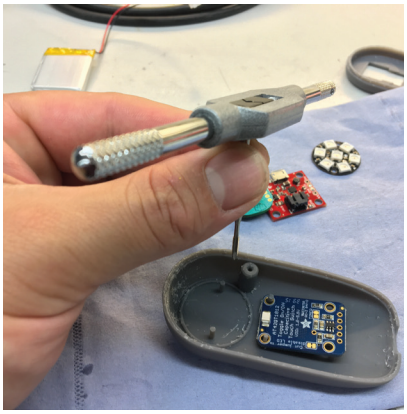


Painting

Soldering



Tapping holes for screws



Uploading the code

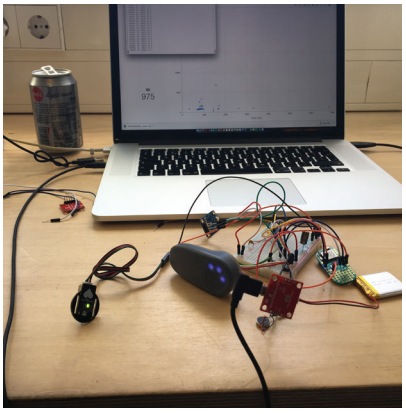


Figure 109. **Assamblage of the prototype**

Figure 110. Finished prototype

9.4 PROGRAMMING

9.4v.1 Internal code of AFi

The code consists of two parts, the internal code of Afi and the code to communicate with platforms outside Afi the device itself, the external code. The external code requires specific technical know-how to write, consequently the task to write this code was outsourced. Therefore, only the internal code of Afi will be discussed here.

An Arduino is only capable of performing one task at a time.. Therefore, a workaround was needed which was achieved by using Finite State Machine [FSM] programming. FSM allows the Arduino to switch between states, effectively making multitasking possible.

The FSM of Afi consists of two parts [Figure 111], on the one hand reading the PPG sensor, on the other the device interaction. The raw code has been provided in Appendix D.

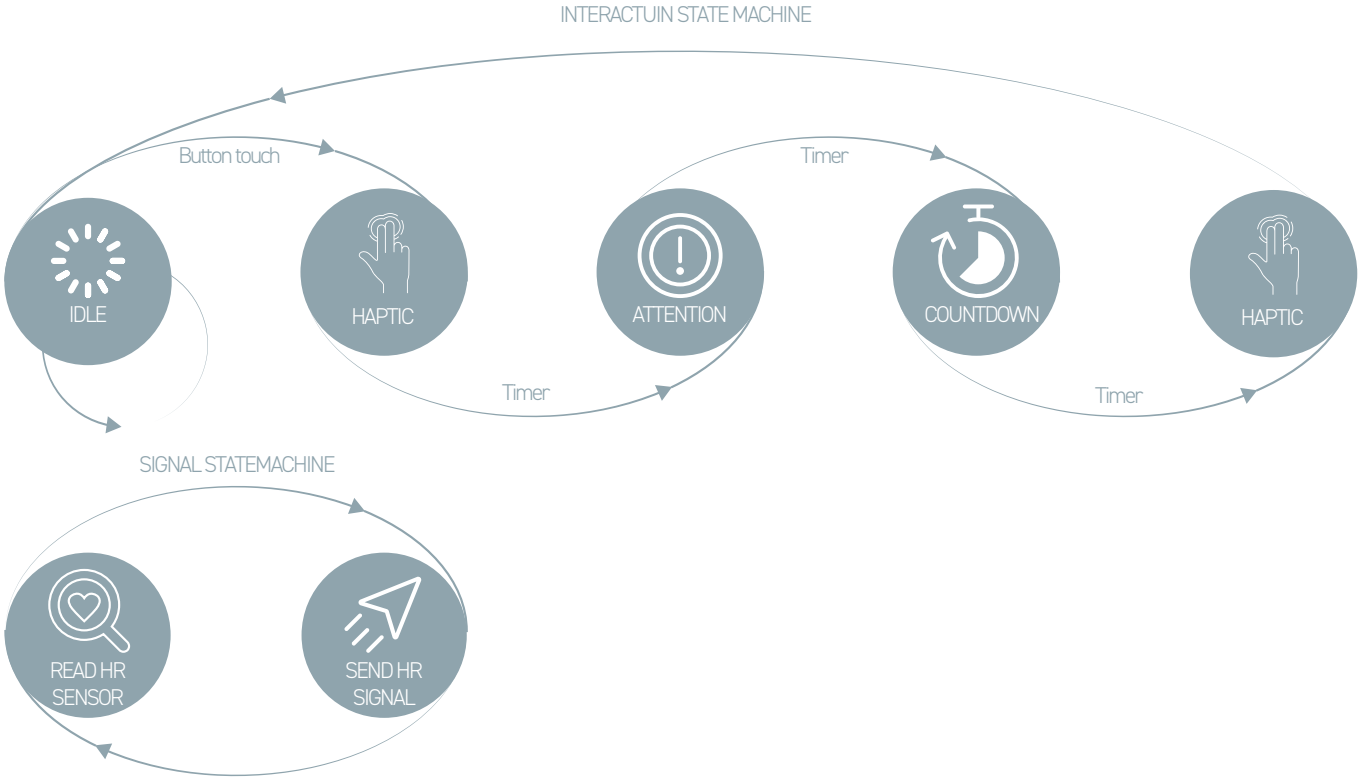


Figure 111. **Above the statemachine for the interaction of AFi, below the statemachine for reading and sending the signal**

Via the Bluetooth connection, a server function is set up where the output from Afi can be made visible. This is done in a web page that shows BPM, HRV and a Lorenz plot [HRV, HRV+1][Figure 112].

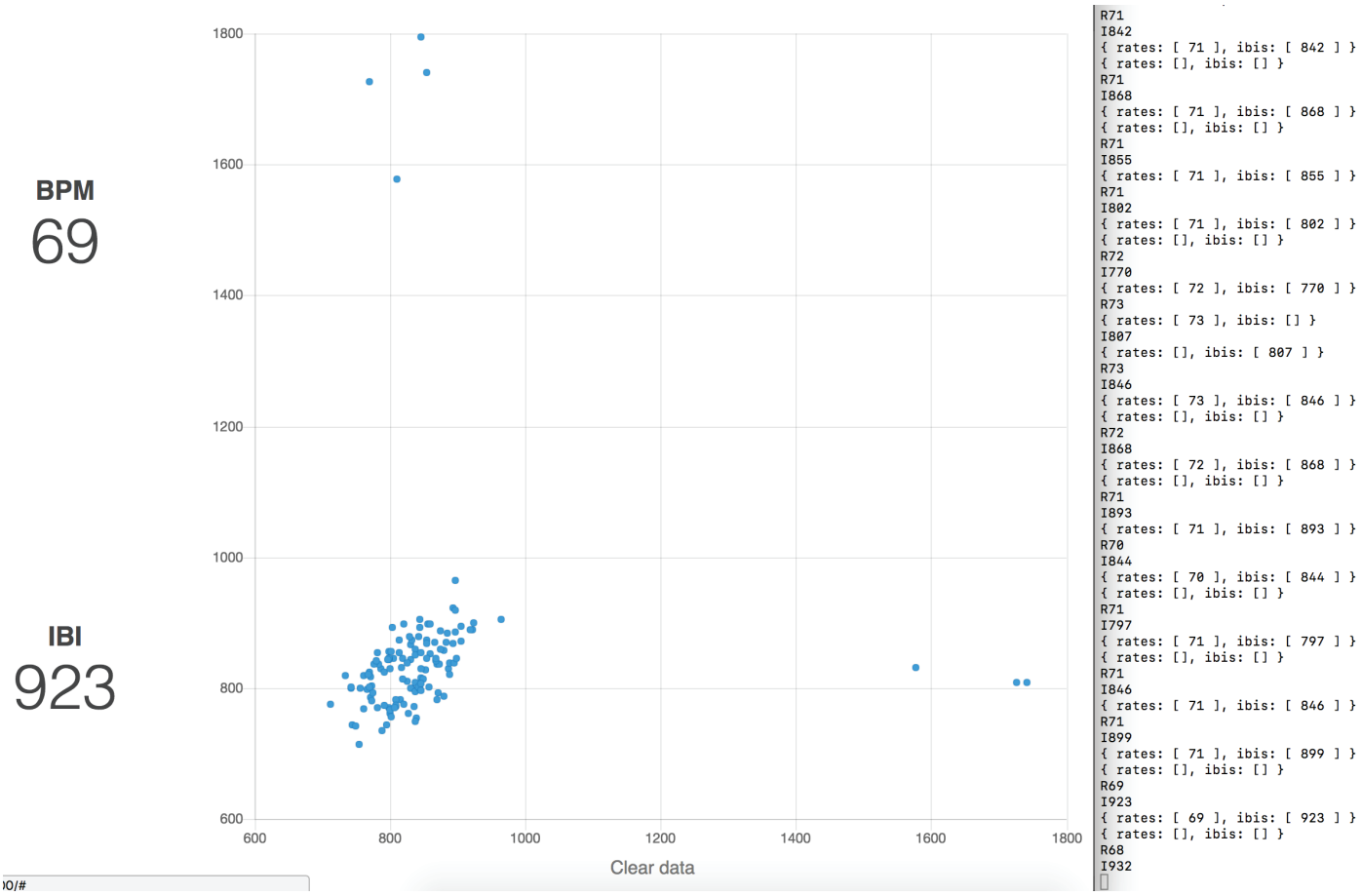


Figure 112. Left: Webpage Right: Datastream from AFi

10. - EVAULUATION

The Afi concept is focused on being able to better diagnose AF than is possible in the current system. To do a better job than the current system, users have to be central, making user evaluation critical. There are two primary types of users, the patient and the healthcare professional. The healthcare professional can be further divided into two sub-categories, the GP and the cardiologist. User evaluations were carried out for each of these (sub)categories.

10.1 PATIENT || USER TEST

10.1.1 Goal

The primary purpose of the patient-user test was to find out if the physical embodiment of Afi makes sense for a regular user, which is the patient that is being tested for AF, and whether Afi meets the requirements of the design brief. Afi has to be a straightforward and an easy to explain device to reduce the time needed by the GP (or his/her assistant) to give out this device.

10.1.2 Methode

The method of the user test was by providing the most-simple explanation of the Afi, once the user can understand and figure out how to use Afi. Furthermore, a series of questions were asked that is based on the requirements of the design brief. Next, to this the interaction feedback was looked at and if these are understood as intentioned. The interview was conducted with 5 potential users.

"I think the size is a bit on the large side for my arm."

"it looks good and is not very annoying."

"When you explain what the lights were I completely got it. However, the lights on its own are a bit confusing."

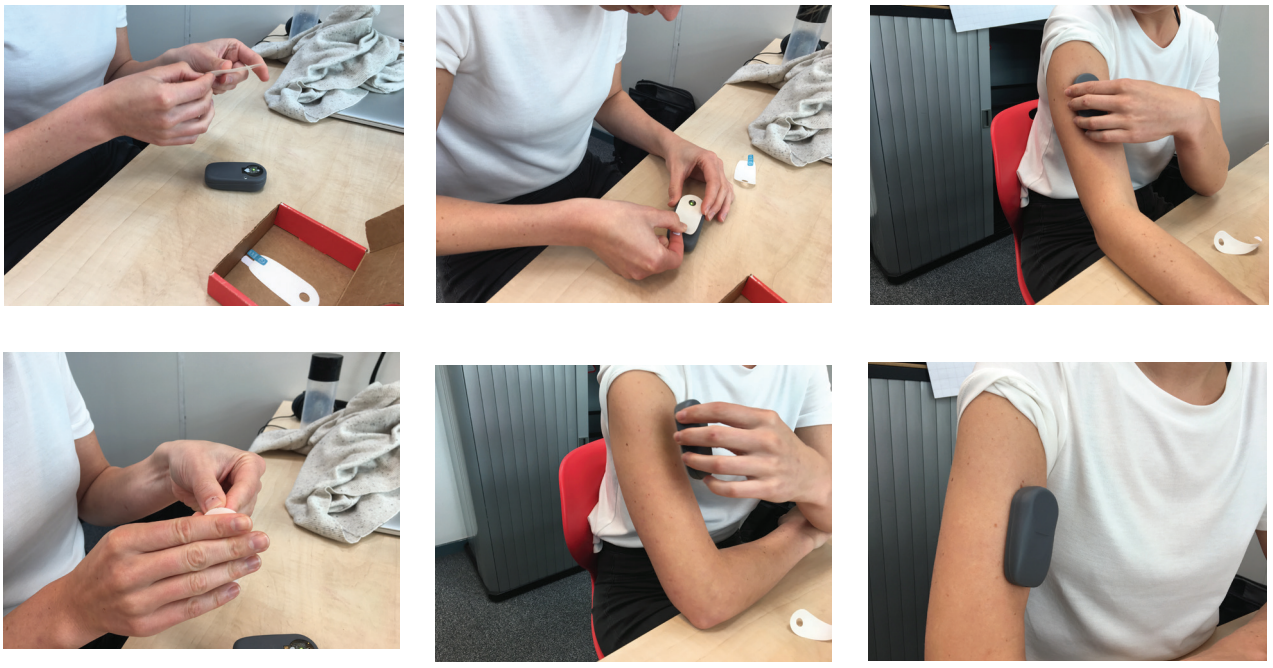


Figure 113. Usertest

From these first user test some conclusions can be drawn:

1. There need to be more visible user clues on the device to accommodate the first time user.
2. The adhesive gave the user enough confidence when it was on. However, they could not believe this at first. This contradiction can be addressed for example with a smaller user manual which pictures of sporting people.
3. For shorter people the device is a bit big, the larger user found the size, not a problem.

"it is so much lighter than expected"

"it still gives me all the freedom to move"

"I think I won't notice the device anymore after several hours"

"The clock is clear enough"

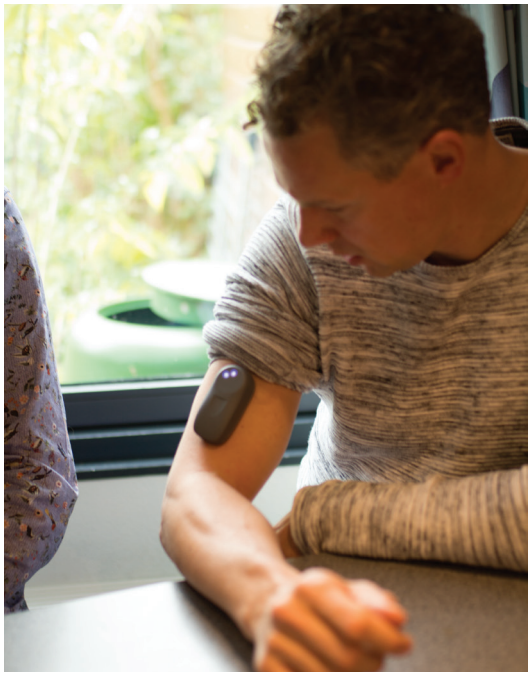


Figure 114. Usertest

10.2 GENERAL PRACTITIONER || USER TEST

10.2.1 Goal

The primary purpose of the GP test is to find out if Afi's system would fit the process of the GP. The secondary goal was to verify that the GP would understand the use of Afi and check if Afi does meet the requirements in the design brief

10.2.2 Methode

The test was conducted in the form of an open interview about the diagnosis process now and how Afi would Impact this. Two GPs were interviewed in Delft.

Besides the interview, to this, the testing procedure that was used for the patient user was also used for the GPs to evaluate if he can understand the application of Afi. Some comments form GPs:

Although the number of interviewed GPs was low and more interviews should be conducted, it is possible to find some value in the interviews.

1. Afi is a smaller device then the devices GPs give to patients to measure at home in the current situation.
2. They see the value of Afi and would like to have it in their practice.
3. The GPs have concerns that the only option for connecting Afi to the body is an adhesive.

"The size is a lot smaller than the blood pressure monitors that we give to patients for a day."

"A holter is not easy to prescribe for a GP, we don't have them here, and the holter does not come to mind when a patient has vague complaints."

"We already have a blood pressure monitor that we give to patients for a day, a device such as this (Afi) could easily be provided to patients in our practice".

10.3 CARDIOLOGIST || USER TEST

10.3.1 Goal

The objective of this user test was to evaluate the concept as a whole, rather than only verifying the requirements of the design brief.

"It would be fascinating to look at this together with a group of cardiologists that are involved in writing the European standards on AF and people from the Hartstichting [and investigate possibilities] for further development."

10.3.2 The interviews

An open interview was conucted with Prof. I C Van Gelder, one of the co-authors of the European AF standards for cardiologists. The entire concept of Afi was discussed and the working principle was shown.

In the interview, Van Gelder was very enthusiastic about Afi and would like to see it further being developed, due to the significant potential she sees.

"We proved that if you take the risk factors down, episodes of AF also will reduce, however not enough. Therefore, we want to detect AF earlier and possible look more at the blood pressure. To do this Afi would be perfect."

"This is enormously exciting, and it fits with the time."

"The cooperation between the GP and the cardiologist is indeed significant."

10.4 CONCLUSION

While most of the reactions to Afi were positive and Afi met most of the requirements of the design brief, some problems have to be addressed based on the insights gained in the interviews.

One is smaller use clues in the form of icons on Afi for the button and the timer clock. These clues are small icons, which are embedded in the housing that gives subtle hints towards the user.

Secondly, a smaller clip-on strap to make Afi useful for people that get an irritated skin from the adhesive sticker.

Thirdly the next iteration of Afi should be smaller; this can reach by manufacturing a PCB with all the electrical components on it, in contrast with the current situation where all the electrical components have their own board.

11. VISION ON THE USER INTERFACES

Besides the physical embodiment of Afi two user interfaces are also part of the full Afi system: the App for the healthcare professional [HCP] and the user/patient app.

When considering the app for the HCP, i.e. the GP and Cardiologists, it must be understood that these are two different types of user, who have different needs for such an app. The various requirements of the GP and cardiologists can be found in chapters 2.4.3 and 2.5.2 respectively. Because of these different needs, there is potentially also a need for two kinds of Apps. However building an app for every type of user is expensive. Therefore, it is recommended to integrate the different needs into one app. This is further elaborated on in the following paragraphs. The app for the user/patient is an essential part of the design of Afi. A patient has to be able to monitor him or herself for an extended period to detect AF; this requires a level of dedication and motivation from the patient. A physical device alone will not achievet his due to its very limited feedback options.

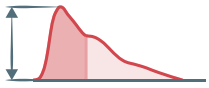
App healthcare professionals

- Different needs
- Vision

11.1 THE APP FOR THE HCP

These various needs arise from the difference in expertise and objectives that a GP and a cardiologist have, as has been explained in chapter 2. To each reach their goals, they require a different kind of information.

While the information needs are in themselves different, it is still possible to obtain all the required information from Afi. The difference in information depends more on the level of processing done by the system than on the sensor type [Figure 115].



PPG pulse

After processing

- Heart rate
- Heart rhythm
- Heart rate variability
- Respiration
- Stroke volume
- Blood pressure trend

Accelerometer

- Activity tracker
- Sleep/awake
- Heart rate
- Respiration

User input

- Symptoms
- Feel of symptoms
- when is an episode

Information outside tool

- Basic patient information
- ECG input
- CHA2DVA2sc score
- BMI

Figure 115. Various types of information possible

Thus, the recommendation for the HCP app would be to build a system that makes it possible to generate variable levels of depth in information [Figure 116]. This will allow one system for the two subcategories of HCP. This difference would allow the GP to use the 'more' processed information, while the cardiologist can look deeper into the system and see the 'raw' information.

The interaction style recommended for this app was inspired by an infographic from the Washington Post (Schaul & Uhrmacher, 2017)[Figure 117]. In this infographic, deeper levels of information [of the US elections] are shown step by step. This style would allow the different levels of the app to interact with each other in a very fluent way.

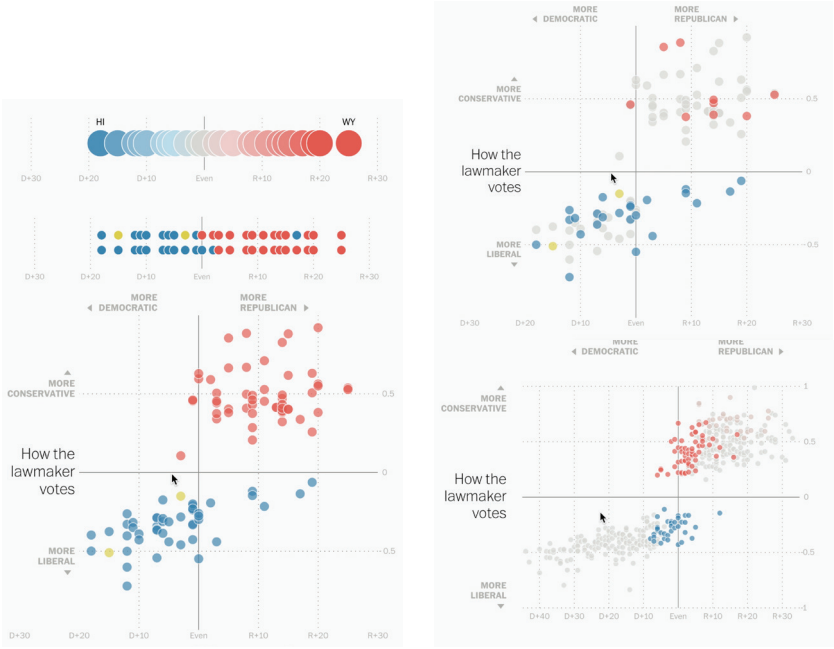


Figure 117. Screenshots of the inforgraphic of the Washington post, scource: https://www.washingtonpost.com

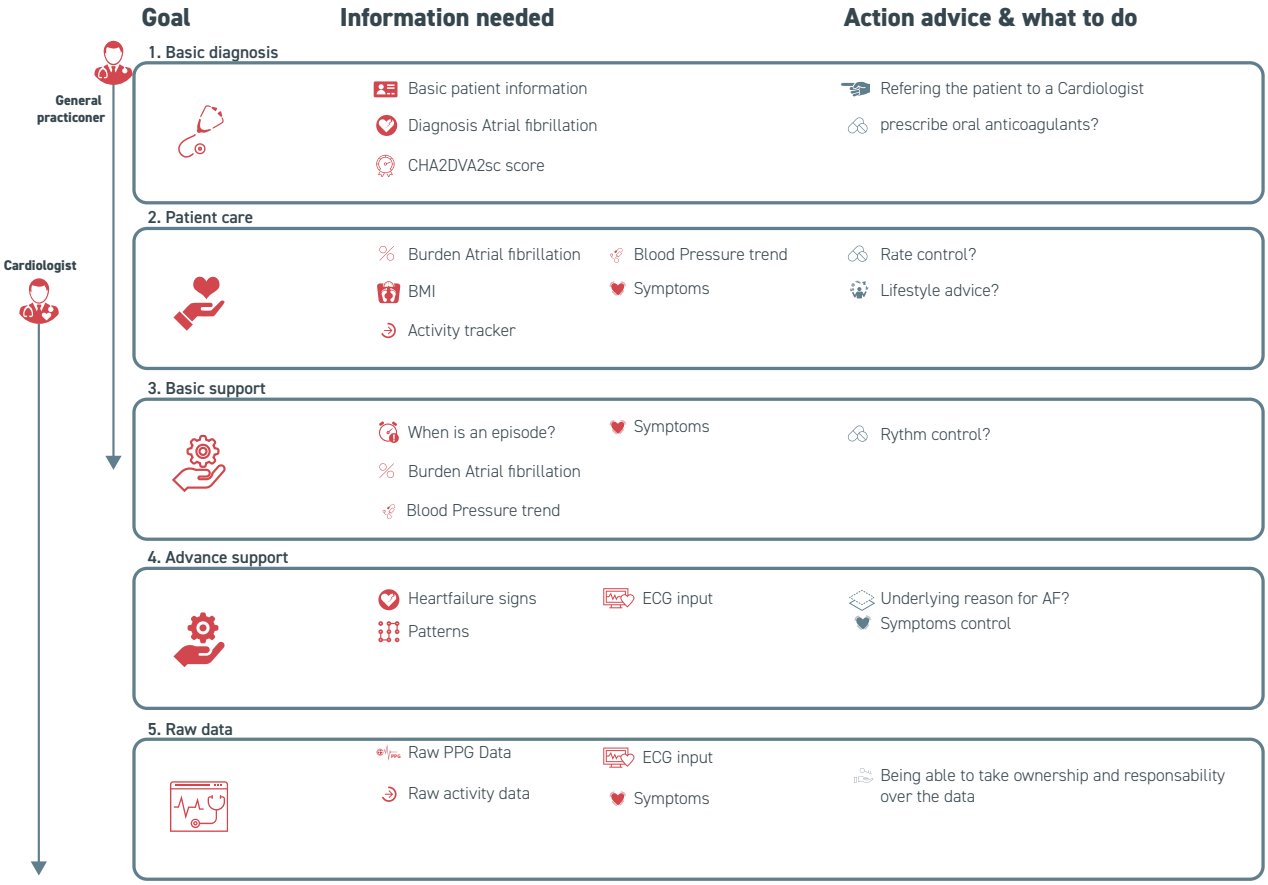
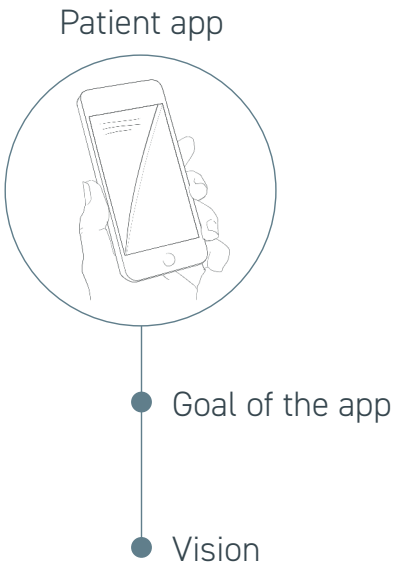


Figure 116. Goals, information needs and what to do with it.



11.2 THE APP FOR THE USER/ PATIENT

The primary objective of the user app is to motivate the user to continue to use Afi for the specified detection period. To achieve this, a patient needs to be involved in the diagnosis process. There needs to be some feedback. However, a patient also can become overly concerned if the wrong kind information is delivered. This can cause a patient to try the wrong things, which may have unintended consequences, such as being worried and rushing to a hopsital.

An app that involves patients in the diagnostic procedure and keeps them engaged by providing simple data, such as heart rate and activity tracking. However, when an episode of AF is detected, the app should 'gently' inform the patient that there is an ongoing episode. With this information, the patient can make an appointment with a GP. The app should also give patients the appropriate kind of education on AF.

12. VISION FOR THE SYSTEM AROUND AFI

12.1 FUTURE VISION

Future design vision:

"A low threshold tool that will create an ecosystem for early detection of heart-related diseases"

The future vision is to build a more extensive ecosystem[Figure 118], an ecosystem is a which relies on eachotehter to exist, around PPG detection. The vast future possibilities, for example with the second derivative of the PPG waveform or glucose level detection, can open up a new world of opportunities for the early detection of diseases in the cardiovascular arena as well as more in general. [Appendix A].

These possibilities would make Afi a veryuseful and versatile tool for GPs and would make sure they would use it often. Besides this, it creates a solution for the third problem to correctly diagnose AF, which is the vagueness of the symptoms. By creating a solution that covers more than AF, it can create a clearer picture and more insight for the GP into a wide variety of symptoms.

12.1.1 Ecosystem for a wide range of diseases

While creating this ecosystem falls outside the scope of this graduation assignment, it has to be noted that this would significantly influence and effectiveness of the AF detection tool itself. Therefore, the solution has to build with modularity in mind, to create the possibility for this ecosystem in the future.

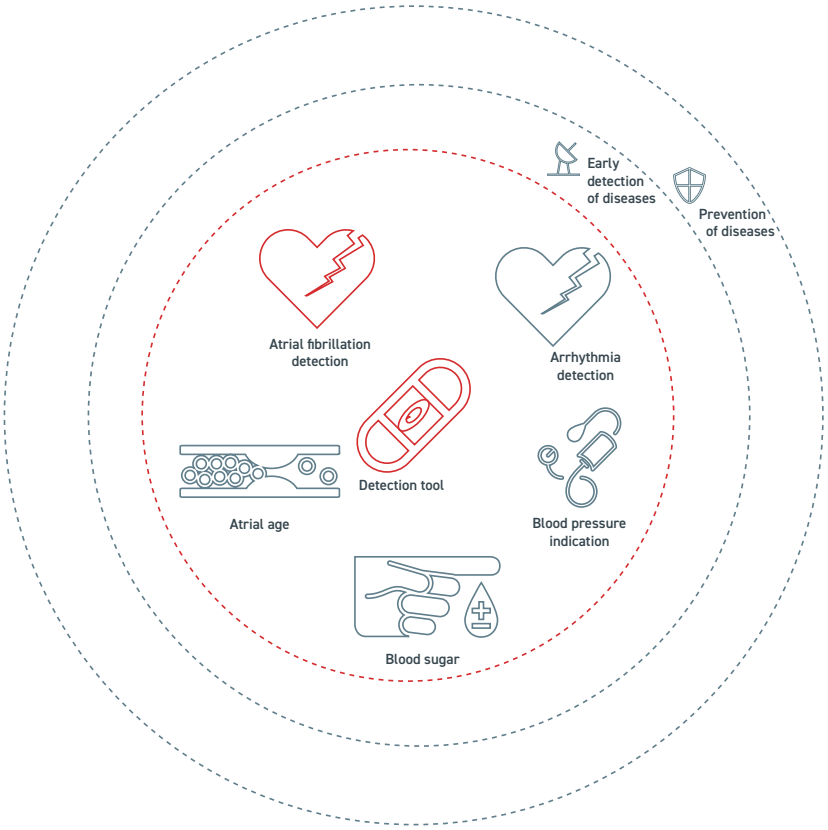


Figure 118. Future health monitoring ecosystem

13. RECOMONDATIONS

This project was a challenge and will be in the future, however it I believe it has a lot of potential. In these recommendations, I will try to show the potential and how to reach these. It will consist out of the part around Afi as it is right now and a part of what the next step could be a total system.

To develop Afi as a viable product further, first of all, there has to be a design for the user app and HCP app, which is needed to complete the concept of Afi. Now the that there is a prototype of the physical part of Afi and know which kind of data is available to show in an app, it is easier to start building an app. User-testing can do this with an iterative process.

Furthermore, I would like to recommend to further develop Afi itself, by reducing the size. A possibility is by making a PCB with the main components on it. Making a custom PCB would allow Afi not only to be a lot thinner but also that the button can be in the same place as the countdown ring. These design changes would reduce the size of Afi significantly.

The next step would be to expand the use of Afi, by first of all detecting multiple arrhythmias. This is a relatively easy step; it would 'only' require an adaptation of the algorithm of AF detection with the Lorentz plot to detect more types of arrhythmias.

A bigger step would be to expand outside arrhythmias and becoming more a general health tool. PPG has potential in showing the vascular age of a patient and a blood pressure trend. This is a vision is futher explaind in chapter 12. Especially blood pressure would be of interested and is considered a holy grail by researchers. However, a fundamental difference can be that these researchers are focusing on getting an exact blood pressure out of the PPG data, which could indeed be hard to do. I believe that HCP does not demand a precise blood pressure number and an indication would be accepted.

To follow up on these steps, I believe on two options, one further development by Philips, two by a Spin-off in collaboration with the Cardiolab.

14. PERSONAL REFLECTION

This final chapter concludes the report by evaluating the project as a whole from the perspective of the graduating student. As a reflection on the overall project and process. This includes some insights that I gained during the project, which will hopefully provide lessons for the future of Cardiolab.

In the very beginning of this project, Philips came with a proposition for an assignment, however, to better fit some requirements of my master track and myself we needed to changes some points. While I still believe that these changes were necessary, I do not think that the changes were communicated enough within the Cardiolab team, leading to some differences in the goals during the project. Also, the assignment evolved during the project. This created a gap between the wishes from Philips and what I believe was the best direction to fulfil the assignment.

A learning point in this is that it would be better to have several meetings with the whole team were the goals and changes during the process are discussed and set. In future, I will try to organise such a meeting with the full team periodically; even this is challenging given scheduling and travel constraints.

The last point is about the complexity of the project: this is something I truly enjoyed. It created challenges that were fun to solve! However, at times, it also made it hard to maintain my schedule, and it sometimes it clouded my view. For example, I dove too deep into the subject of blood pressure measurement using PPG. Which was a lot of fun, however, I could have done with a smaller exploration of the topic, which would have been better for my schedule.

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A. APPENDIX - BLOODPRESSURE

BLOOD PRESSURE MEASUREMENT WITH PPG

PPG has the potential also to measure blood pressure or least give an indication of the blood pressure. This could be a huge breakthrough in healthcare by providing unobtrusive continuous blood pressure monitoring. The technology to do so is still in the first stages of development and Philips believes that is still at least one and a half years away.

There are two ways to extract blood pressure data from the PPG signal. One is to look at the Pulse arrival time, which is the difference between the electric signal of the heart (as measured by an ECG) and the arrival of the blood in the blood vessels, as measured by PPG, over a known distance.

The second way of doing this would be to look at the pulse amplitude of the waveform. Pulse amplitude shows a considerably stronger coherence and better correlation to continuous systolic blood pressure than does pulse arrival time. It also provides theoretical systolic blood pressure estimates that have lower errors (Eric Chua, 2010). Besides, by looking at the second derivative of the wave, an indication for hypertension – which is very closely linked with blood pressure – may be visible. This can be done by looking at the b/a-index(the values in a and b in figure XX) in the second derivative of the PPG waveform that discriminates independently between subjects with essential hypertension and healthy controls. (Elgendi, 2012, p. 21). However, it 's hard to provide an exact value for the blood pressure with either of these techniques. Therefore it is proposed to use a pressure index/trend instead, which is an indication of the blood pressure over time instead of exact numbers, for most medical diagnoses process this should be sufficient instead of the more exact blood pressure number. Shin & min show that the pressure index/trend is statistically significantly correlated with blood pressures, and it suggests that the proposed pressure index is a promising additional parameter for cuffless blood pressure monitoring (Shin & Min, 2017).

Machine learning

The problem with all of these methods mentioned earlier is that they probably need to be calibrated for each patient, maybe even multiple times. New techniques, such as machine learning could solve this problem: "An effective system for an estimate of blood glucose and blood pressure from a photoplethysmograph is presented. The main advantage of the system is that for clinical use it complies with the grade B protocol of the British Hypertension Society for the blood pressure. The method is independent of the person whose values are being measured and does not need calibration over time or subjects." (Monte-Moreno, 2011) This shows that there is a patient to measure blood pressure and even more without calibration, mean an easier device for the user.

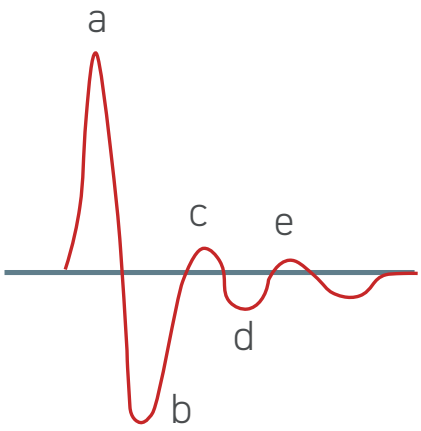
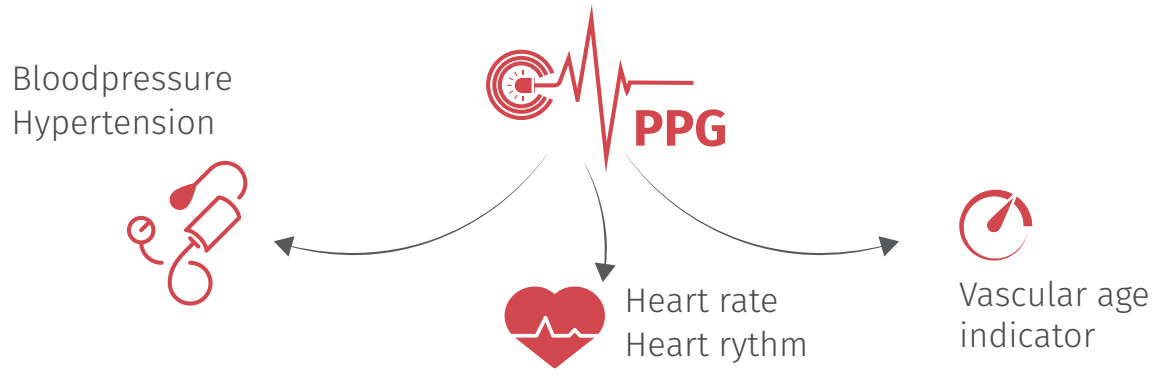


Figure 119. **Second derivative of the PPG waveform**

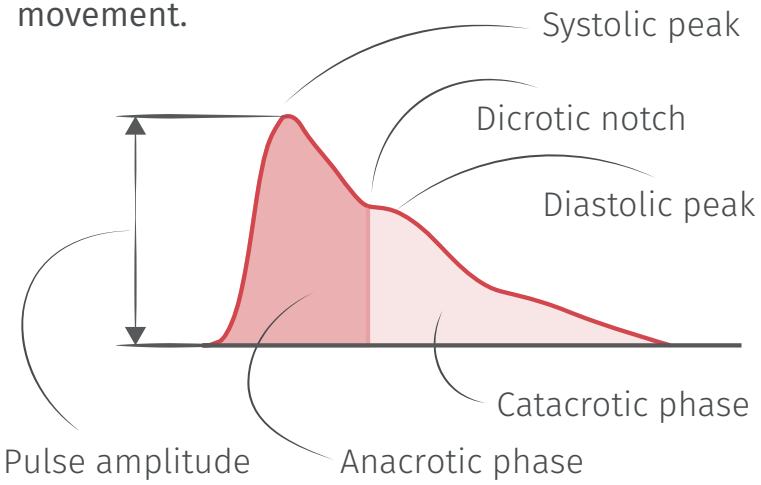
B. APPENDIX - INSIGHTS INTERVIEWS

Insights | PPG is more than heart rate

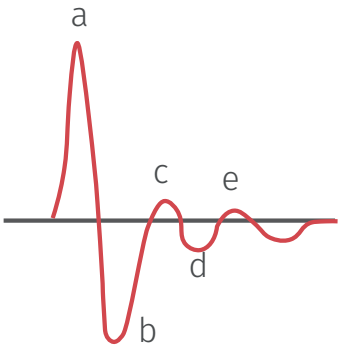
CardioLab



PPG signal refelects blood movement.



Second derivative from PPG signal



Blood presure

Pulse amplitude shows considerably stronger coherence and correlation with continuous systolic blood pressure than pulse arrival time. It also provides theoretical systolic blood pressure estimates that have lower errors. (Eric Chua, 2010, p. 950)

Second derivative and Hypertension

The first and second derivatives of the PPG signal were developed as methods which allow more accurate recognition of the inflection points and easier interpretation of the original PPG wave.(Elgendi, 2012, p. 15)

While imek et al. [69] found that the b/a index discriminates independently between subjects with essential hypertension and healthy controls. (Elgendi, 2012, p. 21)

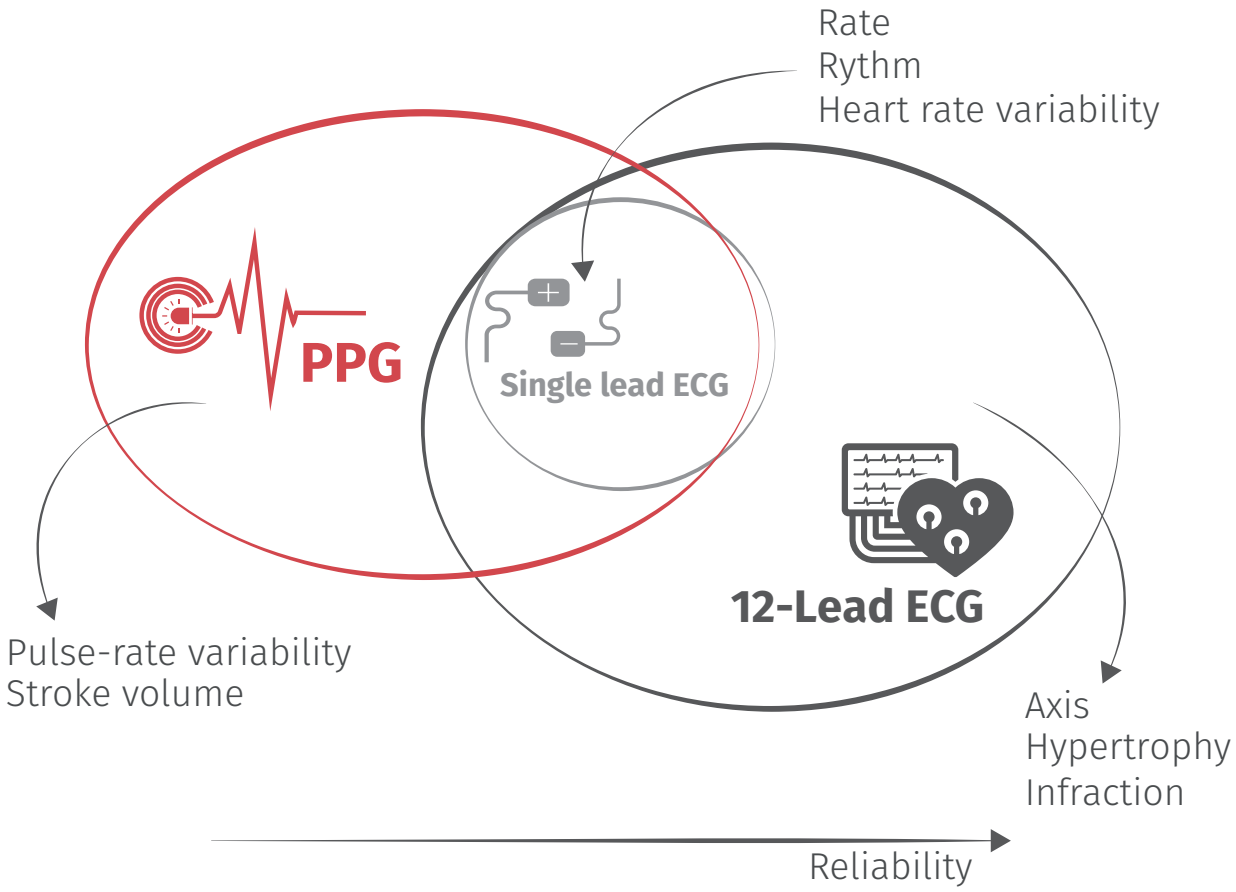
Elgendi, M. (2012). On the Analysis of Fingertip Photoplethysmogram Signals. Current Cardiology Reviews, 8(1), 14-25. doi:10.2174/157340312801215782

Chua, E. C., Redmond, S. J., Mcdarby, G., & Heneghan, C. (2010). Towards Using Photo-Plethysmogram Amplitude to Measure Blood Pressure During Sleep. Annals of Biomedical Engineering, 38(3), 945-954. doi:10.1007/s10439-009-9882-z

Insights | Not PPG vs ECG

CardioLab

PPG can not replace an ECG,however PPG data could still be very valuable.



PPG is a derivative while an ECG is a direct measurement of the electric pulse in the heart

Cardiologist-electrophysiologist will always be intrested in the electrisity of the heart. However after an intial ECG they see posibility for derivative as an trade of for longer term monitoring.

Pepper, E., Harvey, R., Lin, I., & Moss, D. (2007). Is There More to Blood Volume Pulse Than Heart Rate Variability, Respiratory Sinus Arrhythmia, and Cardiorespiratory Synchrony? Biofeedback, 35(2), 54-61. Retrieved March 6, 2017, from https://www.researchgate.net/publication/281574849_Is_There_More_to_Blood_Volume_Pulse_Than_Heart_Rate_Variability_Respiratory_Sinus_Arrhythmia_and_Cardiorespiratory_Synchrony.

Insights | the GP and Cardiologist have different needs

CardioLab

It almost sounds obvious, however it is important to state that for the same desease the GP and Cardiologist look at a different level of data.

"Don't overload me with to much data!"

"I want acces to every bit of data there is."

A reason behind this is that the GP sees a wide variaty of patients and acts as a filter for the specialists.

Furthermore a Cardiologist also wants to know more about the heart, for example if there is an shortness of oxiden

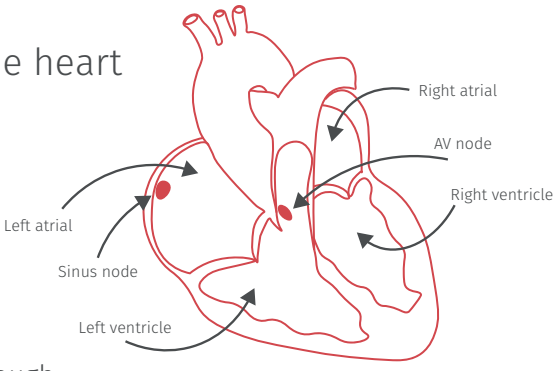
"My ass is on the line."

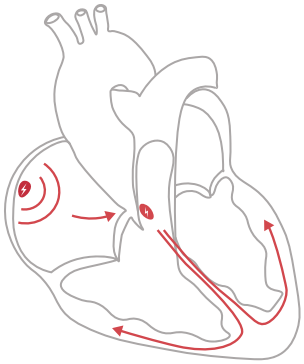
Next to this a cardiologist needs to be able to verify if the data is correct.

Insights | Better understanding of Atrial fibrillation

CardioLab

Anatomy of the heart



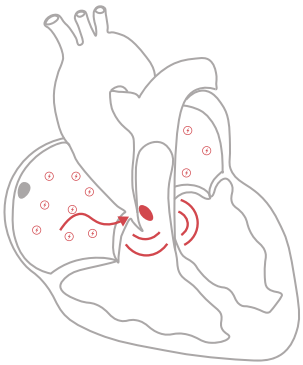


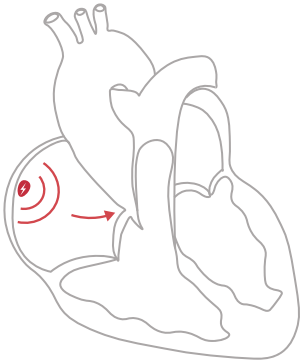
Normal sinus rhythm

Signal spread from sinus node through the atrium to the AV node, which controls the chambers

Atrial fibrillation

Around the atrial are random electric signals, lead to the a pace of 300 to 600 beats a minute in the artrial chambre, resulting in an effective standstile of the atrial chambre. When one of these signals reaches the AV node and the tissue is sensitive the signal (refractory period) is sent through the venrical, leading to a hearth beat.



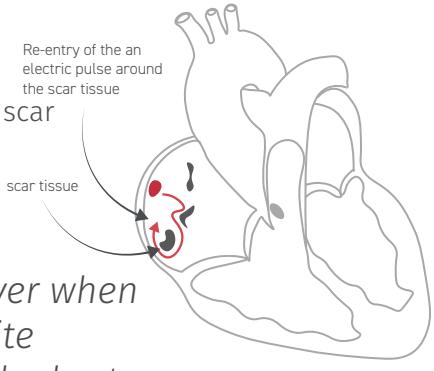


‘Not random’

The ‘random’ signals are from an extra beat in the sinus node. This is very normal and everybody has it.

Re-enter circuits

However these signals re-enter in the atrial chamber due to scar tissue in the hart.



“A healthy heart is like a nicered steak, however when you have Afib, its like a steak with a lot of white tendons in it, these tendons are the scars in the hart and do not conduct the signal right from the sinus to the AV node .”

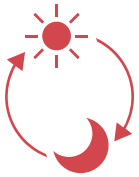
Insights | The daytime coverage

CardioLab

The daytime coverage of a watch solution is to low to accurately measure the burden of Afib.

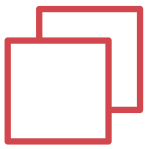
Movement of the wrist can distorted the measurement and even look like AF

Interbeat intervals while there is to much movement will be rejected



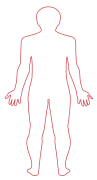
Due to movement alot of the measurements during the day (some 60%) can nog be used to detected AF. At night the measurement is alot better

The low coverage during daytime is a problem. Especially when checking for the burden of afib. This will make your measurement very extrapolated.



A solution can be to have to PPG sensors with different light sensors

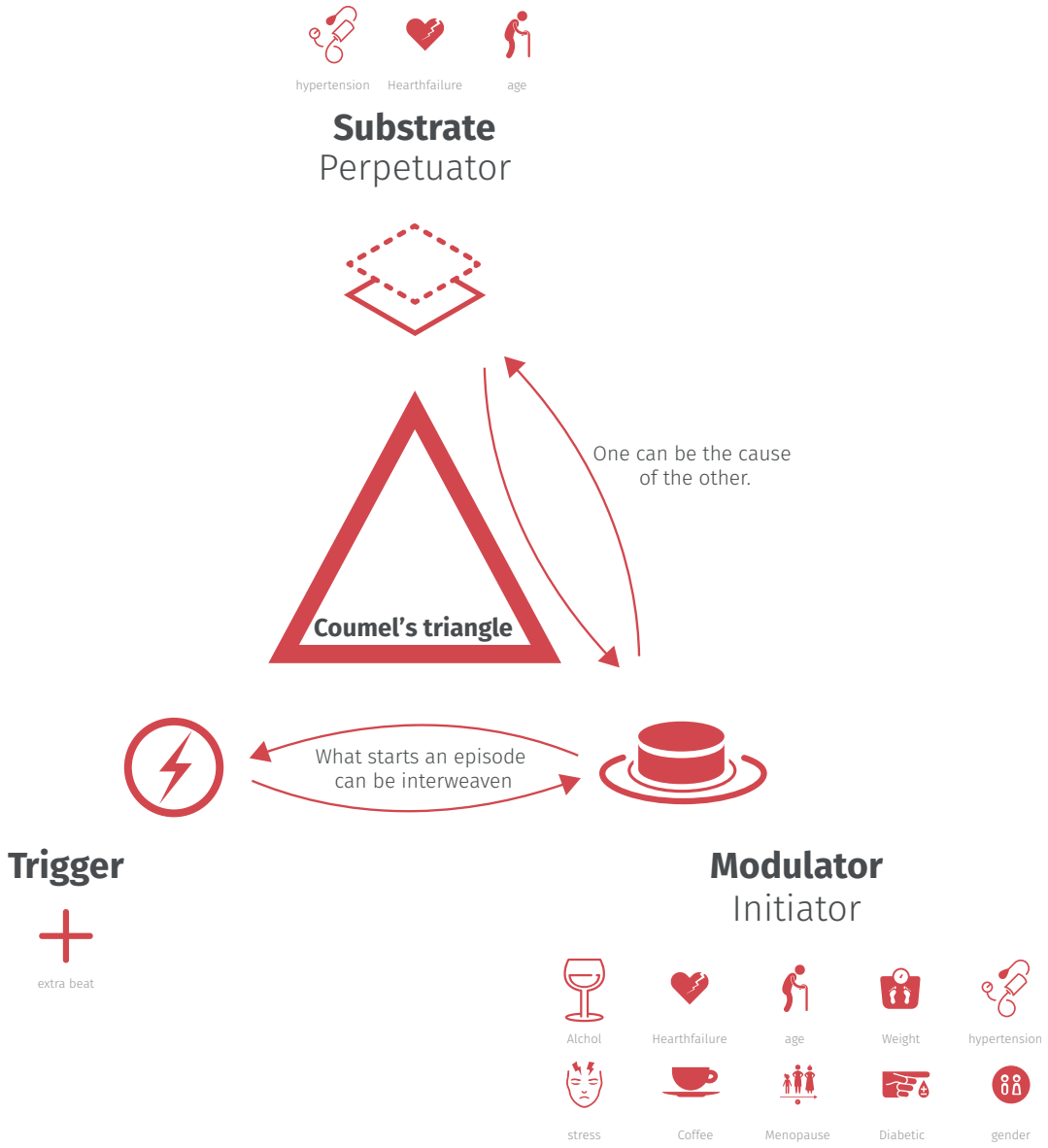
A different place on the body where there is less disturbance by movement could also be a solution



Insights | Triangle of coumel

CardioLab

Coumel's triangle is a good basis in for cardiovascular diseases



Insights | Symptomatic vs Asymptomatic

CardioLab

The symptomatic patient is a different kind of patient then the asymptomatic patient states Issabelle van Gelder.

An Asymptomatic patient already has a lot of other comorbidities

A lot of asymptomatic patients do not notice atrial fibrillation due to their comorbidities. An example in this is Hypertension, which is treated with Beta Blockers. Beta Blockers lower the heart rate, making it harder to feel an episode of atrial fibrillation.

The atrial chamber is already a bit sick.

Due to other comorbidities the atrial is already damaged. (resulting in a worse substrate and modulator). Because of this episodes of atrial fibrillation tent to be longer or even permanent. Therefore these kind patient do not really notice the difference between an episode and normal sinus rhythm.

Insights | Awerness on atrial fibrillation

CardioLab

Often GPs are not aware enough of progresive nature of atrial fibrillation, espially when it is paroxysmal.

It is very difficult to spot paroxysmal atrial fibrillation in the earlier stages.

Due to the short time of the episodes of atrial fibrillation in the earlier stages it is hard to capture one with an ECG or a Holter. Often the diagnosis of Atrial fibrillation depends on the story of the patient. Even this is hard because a GP does not have the time to thoroughly question the patient.

Send home with the advice to reduce stress.

It happens that patients are sent home with the advice to take it easy. In a hope that will reduce the palpitation. It happens that only when the Atrial fibrillation has progressed the patient will be send to the cardiologist.

Patients own lack of understanding on Atrial fibrillation increases anxiety.

Anxiety with patiënts that have just been diagnosed with Atrial fibrillation is common, this due the lack of knowledge they have. N. de Groot and I. Van Gelder believe that education on their disease will greatly reduce and have a positive effect on the behavior of the patiënt regrading their lifestyle.

Aliot, E., Breithardt, G., Brugada, J., Camm, J., Lip, G. Y. H., Vardas, P. E., ... for the Atrial Fibrillation AWareness And Risk Education (AF AWARE) group [comprising the Atrial Fibrillation Association (AFA), the European Heart Rhythm Association (EHRA), Stroke Alliance for Europe (SAFE), and the World Heart Federation (WHF)]. (2010). An international survey of physician and patient understanding, perception, and attitudes to atrial fibrillation and its contribution to cardiovascular disease morbidity and mortality. Europace, 12(5), 626–633. http://doi.org/10.1093/europace/euq109

Insights | Lifestyle can reduce the burden

CardioLab

There is a clear evidance that improving the patients lifestyle can greatly reduce the burden of atrial fibrillation.

Weight reduction

An improvement incardiorespiratory fitness (≥2 metabolic equivalents) during follow-up contributed to a further AF burden reduction in association with weight loss(Van Gelder, 2016, p. 2)

Reducing hypertension

Reducing hypertension could be one of the key factors in supporting patients. Medication is an option here, however it could be desirable to change the lifestyle of the patient. A patient could be helped with reducing the salt intake, reducing stress and proper exercise.

Supporting the patient

The case study of G. Maat (2015) is example how hard is for a patient to stay on track. Especially in a longer term. Longer term support should be desirable.

Maat, G. E., Gerds-Ploeger, H. Z., Mariani, M. A., Gelder, I. C., Brügemann, J., & Rienstra, M. (2015). Relation of overweight and symptomatic atrial fibrillation: A case report. HeartRhythm Case Reports, 1(5), 342-344. doi:10.1016/j.hrcr.2015.06.002

Gelder, I. C., Hobbelt, A. H., Brügemann, J., & Rienstra, M. (2016). Time to implement fitness and reduction of fatness in atrial fibrillation therapy. EP Europace. doi:10.1093/europace/euw287

Insights | The CHA2DS2VSc score as a guideline for screening

CardioLab

I. Van Gelder beliefs that the CHA2DS2VSc score can be a guidline for screening.

Due to the high risk the change is that the heart is already ‘sick’.

There is a growing body of data demonstrating that significant morbidity is associated with silent atrial fibrillation.(F. Russell Quinn, 2014, P 33). Van Gelder states that a reason behind this that the atrial is already sick becuase of the comorbidities.

A lot of comorbidities means a high CHA2DS2VSc score.

Therefore the score is not only important for stroke prevention, it could also be an indicator for silent Atrial fibrillation.

Russell Quinn, F., & Gladstone, D. (2014, January). Screening for undiagnosed atrial fibrillation in the community. Retrieved from http://www.cspin.ca/wp-content/uploads/2014/11/Quinn-Gladstone-2014-Screening-for-AF-in-the-community-Curr-Opin-Cardiol.pdf

Insights | Confirmation of an episode can be helpfull

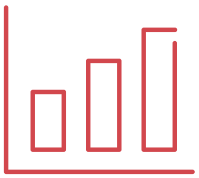
CardioLab

Knowing if and how many episodes of atrial fibrillation is important in the treatment.

Re-insurance of not having an episode.

A patiënt with paroxysmal atrial fibrillation could ‘feel’ an episode while there is non. Leading to more anxiety and unnecessary visits to the hospital.

Keeping track of the increase of the burden over time to improve decision making



It can be important in predicticing the outcome of an ablation to know the Burden of atrial fibrillation

Preventing rapid progression of Atrial fibrillation

To avoid the rapid progression of Atrial fibrillation you could use an long term monitoring device

Shukla, A., & Curtis, A. B. (2014). Avoiding permanent atrial fibrillation: treatment approaches to prevent disease progression. Vascular Health and Risk Management, 10, 1–12. http://doi.org/10.2147/VHRM.S49334

Berkowitsch, A., Neumann, T., Kuniss, M., Brandt, R., Zaltsberg, S., & Pitschner, H. F. (2009). Evaluation Of Atrial Fibrillation Burden Before Catheter Ablation Predicts Outcome After Pulmonary Vein Isolation. Indian Pacing and Electrophysiology Journal, 9(3), 138–150.

Insights | Tracking patients activity

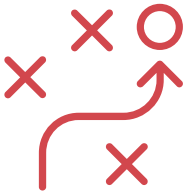
CardioLab

Fifty procent of the interviewed cardiologist found it usefull if ‘secondary data’ was tracked to check the story of the patient and helping in decision making.

Due to time constrains it is hard to find everything with the anamnesis of the patient.

A cardiologist or GP only has about ten minutes with a patient. In such a sort time it can be hard to find everything out. Seeing objective data could improve that.

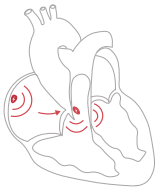
Decision making supported by objective data.



Often the diagnosis of Atrial fibrillation depense on the story of the patient. Certainly in the earlier stages it is hard to record an episode in the time that a GP has for one patient.

C. APPENDIX - INTERVIEW { IC VAN GELDER

What is AF?

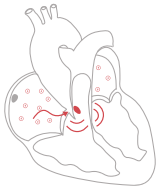


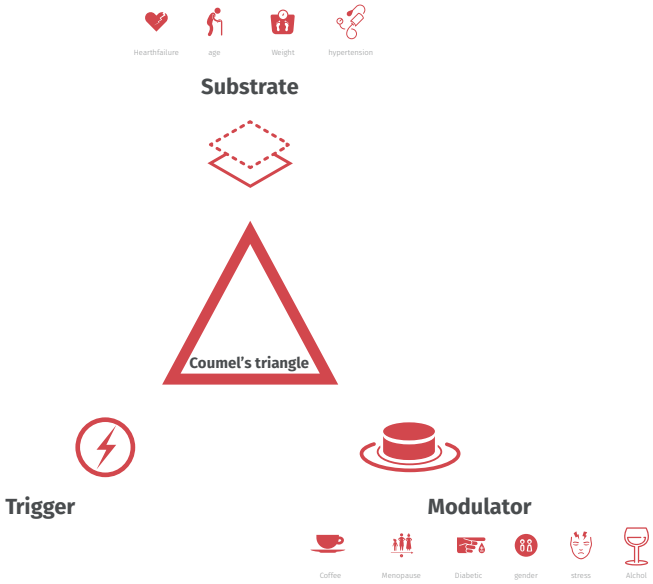
Normal sinus rhythm

Signal spread from sinus node through the atrium to the AV node, which controls the chambers

Atrial fibrillation

Around the atrial are random electric signals, lead to the standstill of the atrial and when one of these signals reaches the AV node and the tissue is sensitive the signal (refractory period) is sent through the venrical, leading to a hearth beat.

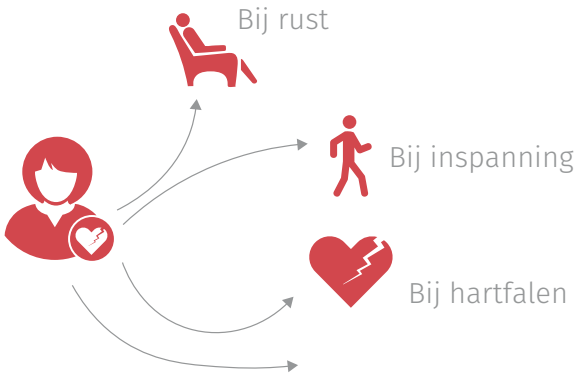




Interview Prof. Isabelle van Gelder

TUDelft CardioLab

Alot of difference in types of AF



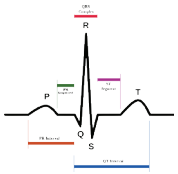
Wat zijn nog meer onderscheiden factoren voor AF?
In uw onderzoek zegt u dat AF te veel over een hok wordt geplaatst, zijn dit factoren waar we onderscheid in moeten maken?

Interview Prof. Isabelle van Gelder

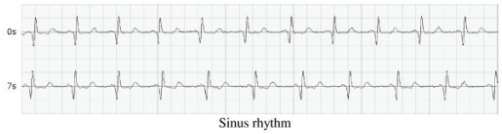
CardioLab

Single lead ECG vs Holter?

Zijn er dingen waar u extra naar kijkt in een ECG voor behandeling?

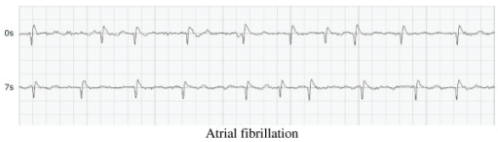


Sinus



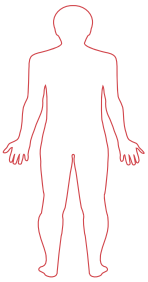
Sinus rhythm

Afib



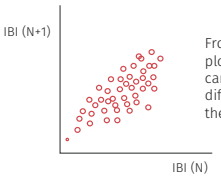
Atrial fibrillation

Kunnen we single lead ECG gebruiken?
Waar zouden we ze kunnen plaatsen om nog een goed resultaat te krijgen?



Gebruikt u de poincare(lorenz) plot?

Poincare plot



From the IBI an poincare plot can be created, a cardiolgist can see alot of diffrent things, one of them is AF

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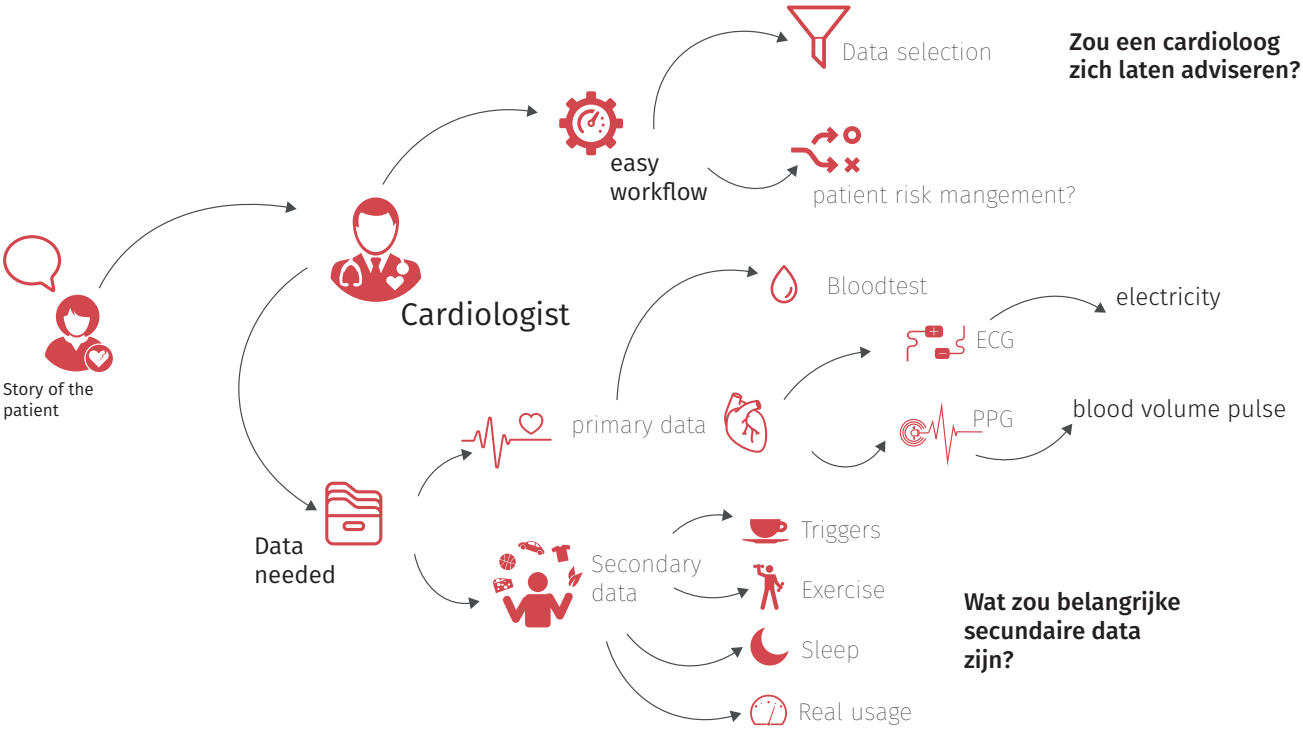

Zou een cardioloog zich laten adviseren?

Wat zou belangrijke secundaire data zijn?

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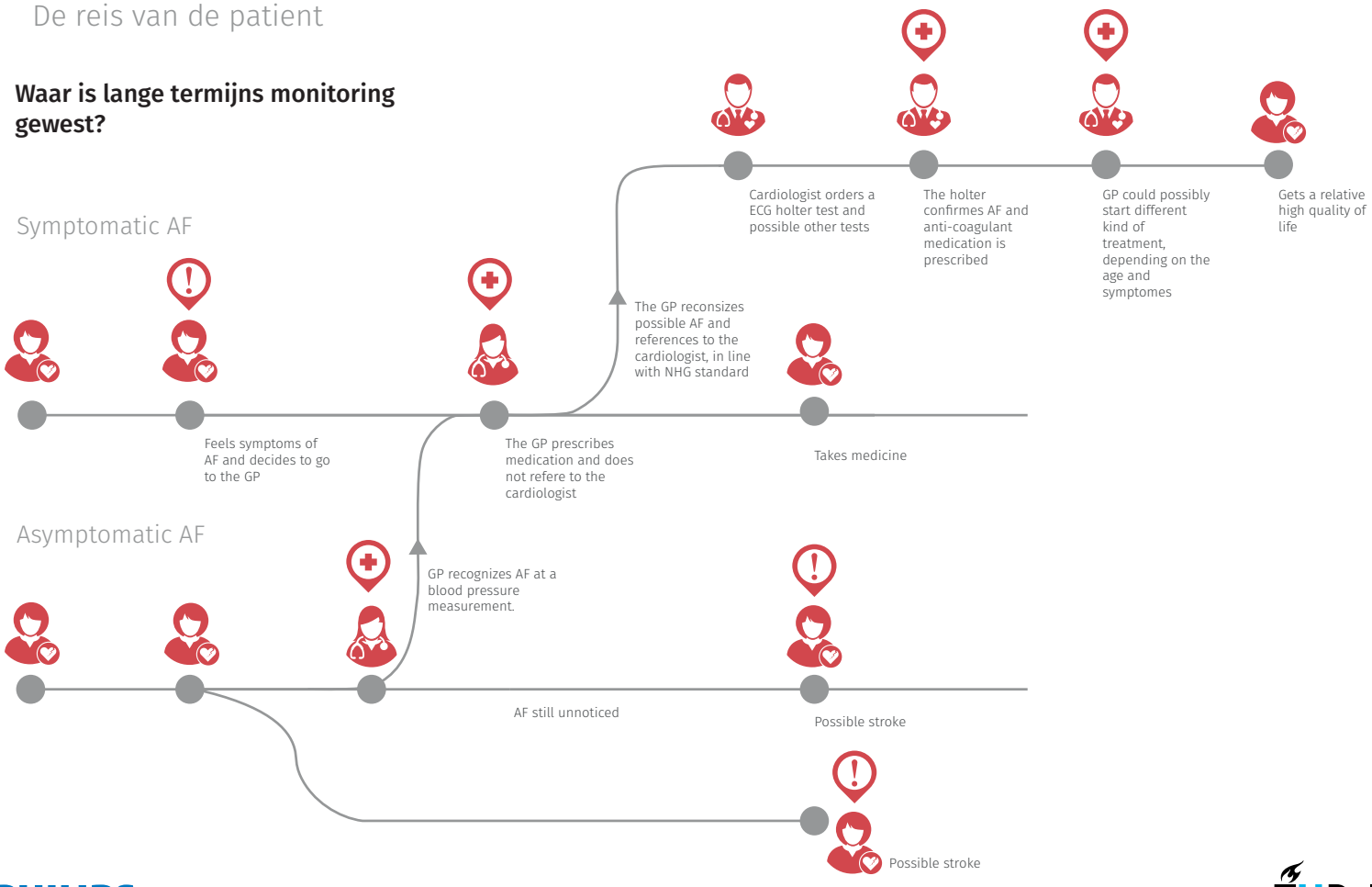
De reis van de patient

Waar is lange termijns monitoring gewest?



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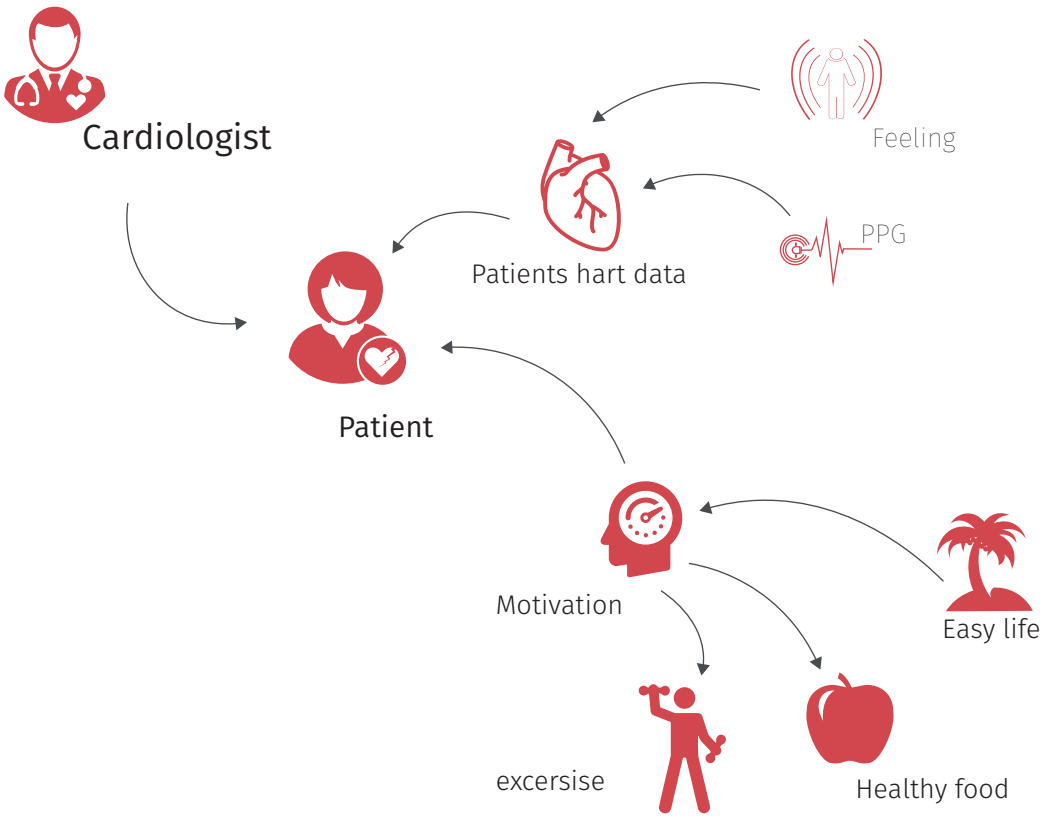

Hoe motiveer je een patient om langere tijd iets te doen?

Wat wilt een patient weten?

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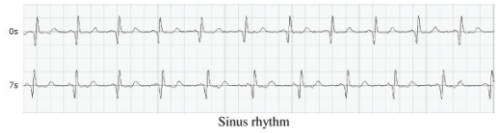
ECG

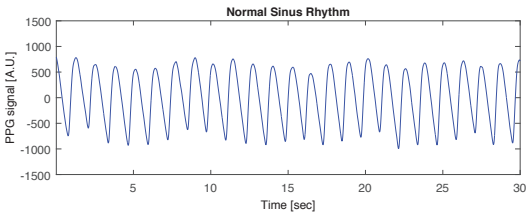
Bent u bekend met PPG en het meten via bloedvolume?

	Non-invasivity	Accuracy	Monitoring
ECG	2	2	1
EGM	0	3	2
ILR	1	2	3
PPG	3	1	3

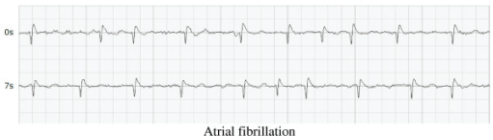
Sinus



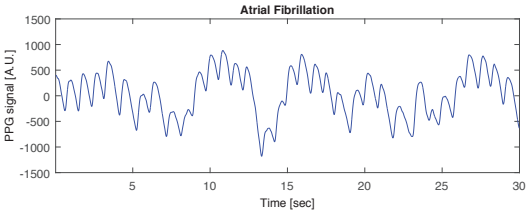
Sinus rhythm



Afib



Atrial fibrillation



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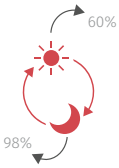
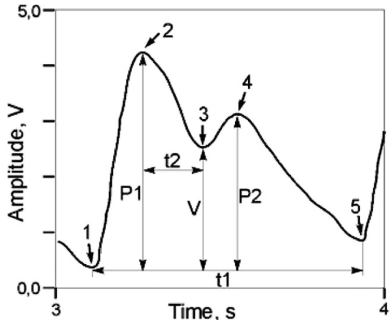
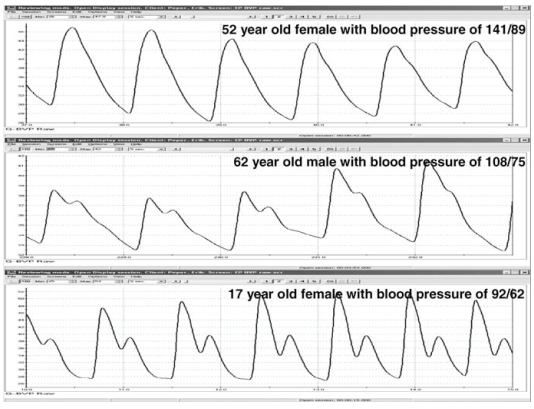
CardioLab

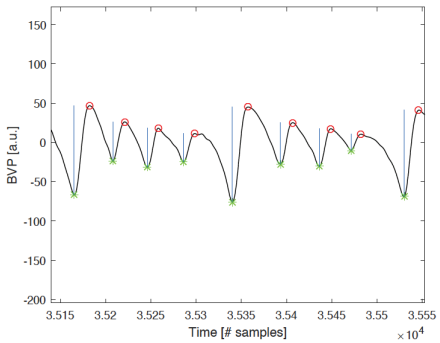
Covarage by movement of the wrist





Example of blood volume pulse signal with amplitude and timing markers. Time t1 (between markers 1 and 5) indicates the interbeat interval and is used to calculate the heart rate. Pulse measure P1 (marker 1) is a measure of pulse amplitude. Volume at V (marker 3) is the indicator of the blood volume influenced by the dicrotic notch.





PHILIPS

TU Delft

C. APPENDIX - INTERVIEWS

Interview cardiologist | Prof. Deckers

He uses the raw data of the ECG and especially of importance is the P-wave of the ritme. He believe showing the P-wave is of crucial importance.

He still manually checks ECG holter data, because he is convinced computers algorithms are not as precise

He only uses the 24-hours ECG varaint. While he is intresseted in longer term monitoring

He would trust a PPG device alsong it is proven to be sensitive enough. He metioned 99%.

He trust the information of the GP, the reason why test are done double to ‘own’ the information in their own hospital.

Triggers are not that important, however rest at night or activities could be intresseting to diagnose the type of AFib. These need to be treated differently.

Interview GP | Interview Dr. Hus

It depends on the situation of the patient if a GP will send a patient to the cardiologist or that the gp will start treatment them self.

The NHG has a standard on Afib, only most GPs do not know this standaard bij hart. An example of this is the NHG says that you should consider the age of a patient for referral to the cardiologist [<65] and Dr. Hus was not really aware of this.

However GPs always check for Afib while checking checking a patient's blood pressure by listening to their heart beat.

An GP gets a overload of information, therefore he is not interested in a detailed report. They rather have a summary with a risk profile in there.[an example is the cardiovasculaire risk management system]

However a GP could be interested in the triggers behind an Afib episode. This could be interesting in their coaching role to the patient.

Interview Researcher | Paul Shrubsole

The Philips watch is not capable of processing the algoritme it self, it needs a cloud or a phone to do that.

PPG signal can not be translated in to an ECG signal. However there are some corrilations between them

Two PPG sensors operating on a different light frequency can reduce movement artifects.

Paul does not think there is a better place than the wrist, even if you could get an higher accuarcy on a different place. The confience is a good trade-off

Interview cardiologist | Dr. J. de Groot

A single lead ECG is enough to discover AFib. However An ECG is always needed.

The triangle of Coumel is a handy tool when think of rhythm disorders. It consists out of the substrate, Trigger and mudulair factors.

Normal sinus rhythm is like a pond where you throw one stone in, white one constant wave as the signal, when afib happens its like its raining in the pond, everywhere are signals.

The poincare plot[Lorenz plot] is a line when the heartbeat has a normal frequency. Its is more and more a cloud when the interval is less dependend on the previous interval, that is when Afib occurs. However this is a indirect way of measuring.

For treatment of a Afib you have 3 pillars.
1) The anticoagulant, to prevent a stroke
2) rhythm control, to control the heart rate to a more normal level, which otherwise would damage the heart even further.
3) Getting a normal sinus heart rate, which only happens when the patient has complaints.

The check at the GP while doing blood pressure measurement are not really effective for finding asymptomatic Afib. Alot of these people never go to a GP.

The low coverage during daytime is a problem. Especially when checking for the burden of afib. This will make your measurement very extrapolated.

When deciding to get a diagnosis one always should ask first what you want to know and what the consequences are of knowing.

There are 3 places where we have a real need for long term monitoring:
1) Patients that had a stroke.
2)Patients that have a diagnostic problem.
3) Patient that where treated, for example with an ablation, to check if the burden is reduced.

Afib is an marker for vascular diseases. It is not proven that afib it self is the cause of the strokes. However it is always associated with stroke.

Interview GP | Berb Galama

A specialist such as a cardiologist already sees a selection, because the GP is the filter for them.

Over-diagnosing patients is a concern. A diagnoses should have a consequence in treatment, otherwise it give a patient only extra stress.

An GP can check a ECG, however they don't do it often and often the diagnoses centre will do the check

Interview cardiologist | Dr. N. de Groot

modulator is meer de opstarter van de episode(inisiator), de subtraat zorgt meer voor het onderhoud(perpetuator) .

Een trigger is bijvoorbeeld een extra hart slag van uit de boezem.

Als je jong bent en je hebt een extra slag is er niks aan de hand, als je wat ouder bent, er is wat schade aan het hart, dan kan de extra slag (triger) in het hart gaan " ronddraaien" om een littekenweefsel(modulator) . Dan is het electrisch signaal verstoord en wordt onderhouden door bepaalde factoren in het hart(substraat).

Bij stress is het vaak Psygische stress.

Bij Atrium fibrilatie kan je een onderscheid maken tussen fisieke status(rust, inspanning) en een ziekte.

Momenteel spreken we over Atrium fibrilleren, maar ondertussen heeft een patient een hoge bloeddruk, een hartafwijking, enz. Wie zegt dat het Atrium fibrilleren bij al die patienten het zelfde is. Is AF een entiteit of is het bij veel patieten verschillend?

Als mensen op de poli komen wil ik meer weten dan alleen het ritme(zuurstof te kort, is de hartkamer verdikt, ect), daarvoor heb ik een 12 lead ECG nodig. Voor de diagnose AF heb ik alleen een single lead nodig.

Zodra ik later in het proces alleen naar het een ritme stornis wil kijken is een single lead ECG genoeg.

Bij een ECG wil het liefst zodicht mogelijk bij het hart, maar een pols zou ook al kunnen.

Een probleem bij de Poincare plot is een episode die korter is dan 5 minuten duurt, de sensitiviteit van de meeting zo erg om laag gaat dat je het niet goed meer kan gebruiken.

Het probleem bij AF detectie zijn de korte episodes die vaak voorkomen.

Het probleem van alleen de PPG technologie nu dat er bepaalde informatie mist, zoals saturatie.

Een huisarts hoeft niet naar het gehele ECG Plaatje te kijken. Voor hem zou het makkelijker om naar een single lead te kijken.

Bloeddruk zou heel erg interessant als extra data voor de cardioloog. (als iemand een hoge bloeddruk heeft zou de puls ampilutede groter moeten zijn)

Bloeddruk is intressant omdat het een belangrijk oorzaak is van AF, als je mensen hiervoor behandeld zouden ze al minder last moeten hebben van AF

Interview cardiologist | Dr. N. de Groot

De oorzaak van AF is nooit ‘iets’ alleen, vaak zijn met mensen met wat overgewicht, hoge bloeddruk, wat ouder. (hogere chad2vasc score) Dit bij elkaar geeft het beeld AF.

Gewicht zou je ook wel van mensen willen bijhouden. Dit kan je gebruiken voor Lifestyle advise geven.

Het gaat om een stukje bewust wordingen van de patient. Door bijvoorbeeld van een healthwatch kan je mensen bewust maken van hun levenstijl. (active reminder)

De extra informatie van een harloge zou goed zijn voor de cardioloog, want we weten niet wat de patient doet als die de poli uit gaat. Hierdoor kan je kijken of de patient zelf een goed beeld heeft van wat die doet.

Het komt vaak voor dat doordat de partner er bij is, de patient de klachten minder uitspreekt.

De groep Asymptomatisch AF is het probleem, die komen pas te laat naar voren. (vaak pas bij een beroerte en zo)

Er wordt momenteel niet gekekennaar de CHAD2VAsc score voor screening, maar dat zijn wel de risico groepen.

Huisartsen sturen vaak te laat pas door. We zien vaak dat mensen die in aanmerking komen voor een ablatie therapie, vaak eerst heel lang bij de huisarts liepen met hartklopping. Daar wordt dan over stress gepraat, tot dat echt een lange episode is van een hartritmestornis.

Huisartsen denken vaak te licht er over. Er zijn veel huisartsen die denken dat AF geen echte ziekte is, want je kan er mee oud worden. Dit is wel waar, maar je morbiliteit en je mortaliteit verhoogt.

Boezemfibrilleren geeft schade aan je hartspier, de schade aan je hartspier onderhoud het boezem fibrilleren. * dus je gaat van aanval gewijs naar pernement hierdoor. Dan ben je te laat.

De therapieen die we hebben werken vaak alleen in een vroeg stadium.

Een huisarts ziet de mensen die wel eens een hartklopping hebben, die daardoor nog het meest gunstig zijn om te behandelen. Als deze tijdig worden behandeld verkom je erger.

Ablatie therapie heeft maar 50% kans op succes, maar er is momenteel niks anders. Soms verdwijnt het niet, maar het kan wel zijn dat ze er minder last hebben door.

De grootste taak ligt bij de huisartsen, daar is de grootste populatie. Huisartsen moeten sneller beslissen.

Interview cardiologist | Dr. N. de Groot

Een systeem moet dus niet alleen detectie zijn, maar ook een awerness creeren.

In het acydemisch ziekenhuis volgens ze de patient een jaar. Dan doen ze 2x 7 daagse holter.

Soms heb je het zelfde probleem met de Holter, waar bij er een artefact zichtbaar is van beweging in de data.

60% procent van de data niet kunnen gebruiken is wel erg veel. (overbewegings artefacten)

Het is geen probleem voor patienten die vaker een episode hebben. Alleen voor juist de patienten die weinig aanvallen hebben en dus baad hebben bij langere termijn monitoring, is 60% te veel.

ze is bereidt op patienten te leveren die wel willen testen.

Interview GP | Berb Galama

A specialist such as a cardiologist already sees a selection, because the GP is the filter for them.

Over-diagnosing patients is a concern. A diagnoses should have a consequence in treatment, otherwise it give a patient only extra stress.

An GP can check a ECG, however they don't do it often and often the diagnoses centre will do the check

Interview cardiologist | Prof. I van Gelder

Het hart bij boezemfibrilleren is als een biefstuk met allemaal vezels er, waarbij het normaal een mooie rode biefstuk is.

De littekens worden een soort van re-entry circuits. Je moet een aantal van deze circuitjes hebben om het boezemfibrilleren te onderhouden. Anders stopt het.

De boezem gaan effectief 400 tot 600 slagen per minuut. Daardoor staan ze effectief stil.

Dus in het begin zijn ze(de boezems) zijn ze een beetje beschadigd, door de onderliggende ziekte(zoals hypertensie). Door het boezemfibrilleren wordt het verder verergert.

Ondertussen wordt de onderliggende ziekte ook erger(zoals hypertensie, dat vaak dan niet wordt herkend als iets wat moet behandeld worden).

Het onderzoek van Isabelle van Gelder gaat om te kijken waarom sommige mensen korte episodes blijven houden en het bij andere erger wordt. Want er zullen ook beschermende mechanismen zijn.

De driehoek van coumel is al een oud en simpele driehoek, we weten nu dat het ingewikkeldere is. Het substraat is zijn. De trigger en de modulator kunnen door elkaar heen lopen, bij de modulator kan je het er over hebben of het met het begin te maken heeft of de voortgang.

Het kan zo zijn dat de modulator voor het substraat heeft gezorgt, bijvoorbeeld een hoge bloeddruk. Dan moet je daar wat aan doen. Alle drie, de trigger, substraat en de modulator dragen bij aan het ontstaan van boezemfibrilleren.

Hier overheen zit nog bijvoorbeeld de genetica.

De modulator zijn vaak meerdere dingen, zoals bijvoorbeeld obesitas.

Mannen krijgen er eerder last van dan vrouwen. Sommige studies laten wel zien dat mannen er meer last van hebben, andere juist vrouwen. Maar de oorzaak is waarschijnlijk dat de onderliggende ziektes heel erg verschillend zijn.

Een belangrijk onderscheid is tussen boezemfibrilleren bij rust of bij inspanning. Vagaal boezemfibrilleren is bij rust en dit komt met name voor bij mensen met minder duidelijke onderliggende hartziektes, vooral bij jongeren. Deze worden behandeld met ablatie en hebben aanvalsgewijs boezemfibrilleren. Dit komt vaak voor

Interview cardiologist | Prof. I van Gelder

bent heeft het vagale de overhand en als je gestrest bent of aan het inspannen bent dan gaat het sympathicus.

Als mensen het tijdens de inspanning krijgen, dan is het niet pluis. Dan moet er iets ernstig aan de hand zijn. Dan hebben ze of ernstig zuurstoftekort of een hele hoge bloeddruk. Als het tijdens inspanning is dan moet je goed zoeken. Vaak is het dan een ernstige onderliggende aandoening waar je iets aan moet doen.

Vagaal (boezemfibrilleren) komt heel veel voor, bij inspanning komt niet heel veel voor.

Vaak begint het allemaal vagaal en later zal het ook op andere momenten er zijn (boezemfibrilleren). Dan is het verder gevorderd(meer progressief).

Vagaal is lastig te ontdekken want het komt op de anamnese (het verhaal) van patiënt aan.

Hierdoor zijn er te weinig gegevens over. Het komt op de voorgeschiedenis van de patiënt aan. Bij normale behandeling heb je maar tien minuten met een patiënt en vraag je te weinig door.

Bij patiënten die het ‘s nach moet je niet gaan behandel een bètablokker. Hierdoor k namelijk erger wordt. (als wi uurs ECG doen en het ‘s nac dan geven we geen bètablok is ook iets wat de patienten

Niet iedereen zal goed door door de tijdsdruk. Maar zelfs overkomt het wel dat ik op h verkeerde moment een bèta geef.

Boezemfibrilleren is een zie oude dag, maar het komt st vaker voor. Dat komt door o leefstijl, waarbij we minder dikker zijn en meer zout ete

Vagaal boezemfibrilleren is bijvoorbeeld ook geassocie langere mensen. Dit zal wel hebben dat de boezems dar zullen zijn en makkelijker re circuits hebben. Deze mens het relatief jong.

Gister een vrouw van 35 op die al een ablatie heeft geh vrij uitzonderlijk. Maar mann komt nog wel vaker voor.

Vrouwen krijgen boezemfibr over het algemeen later.

Het is is altijd een strijd war

Interview cardiologist | Prof. I van Gelder

Boezemfibrilleren wordt toch nog steeds niet goed herkend. Zowel ik als Natasja willen mensen zo vroeg mogelijk ableren. Als ze echt symptomatisch zijn dan zie je de hoogste succespercentage.

Je haalt het boezemfibrilleren alleen maar weg voor de klachten. Niet om langer te leven. Het is bewezen dat het wegpoetsen van boezemfibrilleren niet tot een langere levensverwachting leidt.

Veel meer mensen zijn er tegenwoordig wel mee bezig, Ik krijg wel is de vraag van mensen die een wearable dragen en zien dat ze een hoge hartslag hebben of ze boezemfibrillatie hebben.

Bij de jonge mensen hebben veel minder risico factoren, hierdoor is het risico factor op stroke veel lager.

Het is vaak zo dat mensen met asymptomatisch AF een veel hogere risico factoren hebben.

In de wereld is er het AF screen cortsorcium.

Je zou wel een screening willen hebben voor hoge risico groepen. Deze hebben al een chadvasc van 3. Net een proefdruk binnen van een studie, waarbij mensen een pacemaker lead in hun hart. Dan zie je het risico van een stroke, als je het kort heb dan is het risico wel laag. Maar boven de 24 een episode hebben, dan schiet het risico op een stroke omhoog. Deze mensen voelde deze episodes dus helemaal niet.

Over screening: We hebben nu boven de 65 jaar even de pols voelen, maar dat is niet altijd even gemakkelijk. (het is wel een klasse 2a aanbeveling, dus het moet niet, maar het wordt wel aanbevolen).
Maar ik zou bij mensen met wat hoger risico, boven de 65, hypertensie en diabetes bv. Dat die mensen bij de huisarts wel even laten luisteren.

Het is wel zo dat deze mensen tameklijk een zieke boezem hebben en dat het wel redelijk continu is. Maar tuurlijk is het zo als ze het aanvalsgewijs hebben dat je dan wel net geluk moet hebben.

Het is wel zo dat paroxysme van boezemfibrilleren veel meer last veroorzaakt dan continu. Als het continu is en ze hebben echt veel last van dan komen ze wel. Maar mensen kunnen bijvoorbeeld al een bètablokker hebben, bv voor een hoge bloeddruk. Hierdoor kan het zo zijn dat ze het daardoor niet merken.

Door andere medicatie kunnen ze asymptomatisch worden, zoals een bètablokker. Hierdoor ligt de hartslag al lager. Als mensen een lage hartslag hebben zonder medicatie dan is er waarschijnlijk iets ernstigers aan de hand. Dan kan het zijn dat de sinusknoop het al niet goed doet.

Zonder medicatie en “andere risco factoren” is een anvallen van boezemfibrilleren meer symptomatisch. Want dan merken ze dat het begint.

Interview cardiologist | Prof. I van Gelder

Boezemfibrilleren die aanval gewijs zich voordoet is veel duidelijker aanwezig dan als het permanet is.

Je hebt een voorbeeld, robert tieleman gaat nu ook met een verzekeringsmaatschappij een soort van screening doen. Maar je kan je voorstellen dat er een horloge in een huisartsenpraktijk rond gaat.

Voor de symptomatische patiënten denken wij dat het heel erg belangrijk is om te weten voor deze mensen hoeveel aanvallen ze hebben(hun burden). Om te kijken hoe de progressie is van het boezemfibrilleren. Is het progressief of niet.

Je kan je voorstellen dat bij een lagere burden je niet altijd hoeft te antistollen. Hoe veilig anti-stollen is, niemand neemt graag pillen en helemaal veilig is het nooit.

Over de reveal: Deze zijn eigenlijk hiervoor niet geschikt. Ze kunnen er wel twee jaar in zitten, maar het is een te grote ingreep, alle data moet bekeken worden en het er uit halen is ook hartstikke lastig.

Als een symptomatische patiënten de burden kan bijhouden kan die er wel zelf meer mee doen.

Het voordeel van zulke systemen is ook om te kijken hoe lang een episode al duurt. Als het bv onder de 24 uur is dan kan je nog een cardioversie doen.
Maar ook bijvoorbeeld een huisarts die kan kijken of een patiënt dan wel echt AF heeft wanneer die klachten heeft. Hierdoor kan de huisarts zien of dit wel de oorzaak was van de klachten of dat die verder moet zoeken.

Het kan ook dienen als reinsurance dat er niks aan de hand is. Hierin kan het mensen erg ondersteunen. Hierdoor kunnen mensen ook zelf thuis kijken of ze last hebben.

Behoefte van de cardioloog:

Je zou ook wel wat willen weten over de burden en de relatie met klachten.

Bij onderzoek momenteel (holter/ecg) doen we het nu om boezemfibrilleren een keer gezien te hebben. Het is niet zo dat we net zolang kijken dat we het zien, dat is veel te duur.

Het blijft een belangrijke vraag hoeveel klachten iemand echt heeft voor dat je een ablatie doet.

Mensen kunnen erg overdrijven door de angst voor boezemfibrillatie.

Wij denken ook dat elke dag bewegen leidt tot minder boezemfibrilleren. Het gaat hier over moderate exercise

Interview cardiologist | Prof. I van Gelder

Boezemfibrillatie is ook wel gerelateerd aan duursport.

Wij proberen hier te doen aan integrated care, waarbij de verpleegkundige doet aan angstreductie maar ook de patiënt probeert aan het bewegen te krijgen. Hierbij is het dus al een stuk lifestyle management en ook de onderliggende ziekte goed behandelen.

Op het gebied van lifestyle managment zijn er goede resultaten, er is een cardioloog in australië, die heeft onderzoek gedaan. Deze mensen konden 24 uur per dag ergens feedback krijgen, ze gingen hierdoor enorm afvallen en bewegen, met als resultaat dat hun bloeddruk naar beneden ging. Alles ging daardoor beter.

Als je lifestyle op een of andere manier aan de patiënt kan meegeven, dan zijn wij er enorm geïnteresseerd. Ik geloof in allerlei pillen, maar wat hij laat zien(die cardioloog in australië) dat als je gezond leeft en beweegt, dan gaat je bloeddruk naar beneden.

Het is wel vaak zo dat de mensen terugvallen als de begeleiding wegvalt.

Het zou voor patiënten interessant zijn om meer van de ziekte af te weten, zodat er wat van val te leren. Maar een keerzijde is nu dat mensen altijd hun gegevens opvragen, niet omdat ze ontevreden zijn maar omdat ze meer willen weten. En is voor patiënten niet mogelijk om alles te weten.

Als cardioloog wil je wel de data zelf kunnen verifiëren, want jij staat straks achter het hekje bij het tuchtcollege als je iets verkeerds doet. Dit is anders bij de huisarts.

Over PPG en ECG:

Bij het meten van de bloedvolume met PPG zie je het missen van de boezem contractie en een stuk van het vollopen van het het hart.

In een single lead ECG is het niet altijd even makkelijk om te zien of het sinusritme is met een paar extra slagen of boezemfibrilleren. Het kan wel, maar dan moet je wel de goede leads hebben waarop je de P-toppen goed kan zien.

De lage coverage van de PPG technology op de pols maakt voor asymptomatisch boezemfibrilleren niet uit. Dat komt niet aan op een paar dagen. Maar als je naar de AF burden wilt kijken dan maakt de lage coverage het onmogelijk.

Interview cardiologist | Prof. I van Gelder

Stel dat je via het bloedvolume de bloeddruk kan meten is dat essentieel. Het is hier in niet belangrijk dat het heel exact gebeurt. Het is al goed dat je weet of het hoog is of laag en dat je het ongeveer kan vergelijken.

Als je het op een moment valideert(eikt) en dan kan zien of het omhoog of omlaag gaat, dan is het al goed. Het gaat niet om het getal.

D. APPENDIX - CODE ARDUINO

```
//STATE MACHINE ONE

#define IDLE_LED 0
#define VIB 1
#define ATTENTION 2
#define ledCountDown 3
#define LED_OFF_WAIT_ONE 4
#define LED_OFF_NOVIB 5
#define LED_OFF_WAIT_TWO 6

uint8_t fsm_state = IDLE_LED;
uint16_t msCounts = 0;

//STATE MACHINE TWO - HARTBEAT

#define HARTBEAT 0

uint8_t fsm_hart = HARTBEAT;
uint16_t msCounts2 = 0;


//HEARTRATE SETUP
#define heartratePin A1
#include <DFRobot_Heartrate.h>

unsigned long lastBeatTime = 0;
DFRobot_Heartrate heartrate(DIGITAL_MODE);

//TIMER
unsigned long previousMillisVib = 0;
unsigned long previousMillisVib2 = 0;
unsigned long previousMillisCount = 0;
unsigned long previousMillisCountdown = 0;

//Intervals-timer
const int Vib_time = 90;
const int NoVib_time = 110;
const int Count_time = 400;

//LEDarray
const int ledList[] = { 7, 2, 3, 4, 5, 6, 1};
const int interval = 800; // millis between ticks
unsigned long lastTickTime = 0;
unsigned int  idx = 0; // indexpointer to the array
```

```
//FASTLED SETUP
#include "FastLED.h"
#include "pixeltypes.h"
#include "fastled_progmem.h"

#define __INC_COLORUTILS_H

#define NUM_LEDS 7
#define DATA_PIN 5
#define CLOCK_PIN 13
CRGBArray<NUM_LEDS> leds;

//Setup overige
const int motorPin = 2;
const int buttonPin = 3;
int buttonState = 0;



void setup() {
  delay(1000);
  Serial.begin(19200);
  FastLED.addLeds<NEOPIXEL, DATA_PIN>(leds, NUM_LEDS);
  pinMode(motorPin, OUTPUT);
  pinMode(buttonPin, INPUT);
  pinMode(LED_BUILTIN, OUTPUT);

}

void loop() {
  unsigned long currentTime = millis();


  // switch (fsm_hart)
  // {
  //STATEMACHE 1
  //  case HARTBEAT:

  uint8_t rateValue;
  heartrate.getValue(heartratePin); ///< A1 foot sampled values
  rateValue = heartrate.getRate(); ///< Get heart rate value

  if (rateValue)  {
    String rateString = "R";
    rateString.concat(rateValue);
    Serial.print(rateString);

    int ibi = millis() - lastBeatTime;
```

```
  lastBeatTime = millis();
  String ibiString = "I";
  ibiString.concat(ibi);

  Serial.println(ibiString);


}
// }


switch (fsm_state)
{


  case IDLE_LED:
    buttonState = digitalRead(buttonPin);
    if (buttonState == HIGH) {

      //TIMER AAN VOOR VIB
      previousMillisVib = currentTime;
      //VOLGENDE STATE IS VIB
      fsm_state = VIB;
      msCounts = 0;

    } else {
      (buttonState == LOW);
      {
        FastLED.clear ();
        FastLED.show();
        fsm_state = IDLE_LED;
        msCounts = 0;

      }
    }
    break;


  case VIB:
    //vib button
    digitalWrite(motorPin, HIGH);

    if (currentTime - previousMillisVib >= Vib_time)  {
      digitalWrite(motorPin, LOW);
      // Serial.print("buzzzz");

      //TIMER AAN VOOR LEDS
```

```
      previousMillisCount = currentTime;

      //VOLGENDE STATE IS ATTENTION
      fsm_state = ATTENTION;
      msCounts = 0;
    }
    break;


  case ATTENTION:
    //TIME THAT THE LEDS ARE ON
    if (buttonState == HIGH) {
    }
    //Serial.print("light");
    fill_solid( leds, NUM_LEDS, CRGB(10, 10, 40));
    leds[0] = CRGB::Black; //to show which state it's
    FastLED.show();
    if (currentTime - previousMillisCount >= Count_time) {
      fsm_state =  ledCountDown;
      msCounts = 0;
    }

    break;


  case ledCountDown:
    // leds[0] = CRGB::Blue; //to show which state it's
    if ((currentTime - lastTickTime) > interval) {
      //  Serial.print("LED: ");
      // Serial.print(ledList[idx]);
      //  Serial.println(" goes off");
      // turn of led using
      leds[ledList[idx]] = CRGB::Black;
      FastLED.show();
      // I cannot test this obviously...

      idx++;
      lastTickTime = currentTime; // start counting time again.

      if (idx > 7) {
        // Serial.println("End of list, state goes to idleState");
        // if end of list is reached.
        idx = 0;

        previousMillisVib2 = currentTime;
        fsm_state = LED_OFF_WAIT_ONE;
        msCounts = 0;
      } // if currenttime
```

```
      }
      break;


    case LED_OFF_WAIT_ONE:
      //leds[0] = CRGB::White; //to show which state it's in
      digitalWrite(motorPin, HIGH);
      // Serial.print("buzzzz");
      if (currentTime - previousMillisVib2 >= Vib_time)  {
        // Serial.print("stop");
        digitalWrite(motorPin, LOW);
        previousMillisVib2 = currentTime;
        fsm_state = LED_OFF_NOVIB;
        msCounts = 0;
      }

      break;


    case LED_OFF_NOVIB:

      if (currentTime - previousMillisVib2 >= NoVib_time)  {
        // Serial.print("stop");
        previousMillisVib2 = currentTime;
        fsm_state = LED_OFF_WAIT_TWO;
        msCounts = 0;
      }

      break;


    case LED_OFF_WAIT_TWO:
      digitalWrite(motorPin, HIGH);
      // Serial.print("buzzzz");
      if (currentTime - previousMillisVib2 >= Vib_time)  {
        //  Serial.print("stop");
        digitalWrite(motorPin, LOW);
        fsm_state = IDLE_LED;
        msCounts = 0;
      }
  }

  if (msCounts < 0xFFFF) // Don't let the msCounts overflow
  {
    msCounts++;
  }
}
```