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Wien, 27. August 2020

Niloufar Chakhmaghi

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Kurzfassung

Heutzutage spielt Technologie eine wichtige Rolle bei der Verbesserung der Lebensqualität der Patienten und des Gesundheitswesens. Eine Vielzahl von Krankheiten und ihre Symptome können überwacht und Daten von tragbaren Geräten analysiert werden, um das Verständnis des Krankheitsverlaufs zu verbessern. Als Beispiel hierfür entwickelte das Fraunhofer AICOS einen Algorithmus zur regelmäßigen Überwachung der Gangparameter von Parkinson-Patienten, indem Daten von den Smartphones der Patienten gesammelt wurden. Die Daten der überwachten Patienten können während ihres Routinelebens leicht und passiv gesammelt werden, was für Neurologen hilfreich sein könnte, um das Fortschreiten der Krankheit objektiv zu erfassen. Die Schnittstelle für Neurologen muss jedoch so gestaltet sein, dass sie ihren Praxen adäquat ist. Diese Arbeit zielt zunächst darauf ab, wichtige Faktoren für Neurologen zu identifizieren, um das Fortschreiten der Parkinson-Krankheit zu bewerten und Medikamente anzupassen. Das zweite Ziel ist das user-centred design eines Webanwendungsprototyps zur Visualisierung der Gangprobleme. Über diese Webanwendung können Neurologen genau über das Fortschreiten der Gangstörungen der Patienten informiert werden. Um dieses Ziel zu erreichen, wurde ein benutzerzentrierter Entwurfsprozess verwendet. Basierend auf einer Literaturrecherche wurde zunächst ein erster Prototyp erstellt, der nach Interviews mit Neurologen durch verschiedene Iterationen verbessert wurde. Anschließend wurde der Prototyp von Visualisierungsexperten bewertet, um mögliche visuelle Probleme zu beseitigen. Verschiedene Interviews mit Neurologen und Visualisierungsexperten bewerteten den Prototyp aus zwei verschiedenen Perspektiven, was zur Entwicklung des endgültigen Prototyps führte. Der endgültige Prototyp erfüllt nicht nur die Anforderungen der Neurologen, sondern auch die Vorschläge der Visualisierungsexperten, um ein umfassendes Design zu erreichen. Infolgedessen könnte der endgültige Prototyp genaue Daten für Neurologen liefern, um verschiedene Gangprobleme bei der Parkinson-Krankheit zu bewerten.

Abstract

Nowadays technology plays an important role in improving the quality of life (QOL) of patients and health care. A variety of diseases and their symptoms can be monitored and data gathered from wearable devices can be analysed in order to enhance the understanding of disease progression. As an example of this, Fraunhofer AICOS designed an algorithm for regularly monitoring gait parameters of Parkinson's patients by gathering data from the patients' smartphones in their pockets. The intended patients' data can be gathered by patients easily and passively during their routine lives, which could be helpful for neurologists to detect the disease progression objectively. However, the interface for neurologists needs to be designed to adequately fit their practices. This work firstly aims to identify important factors for neurologists for evaluating Parkinson's disease progression and adjusting medications. The second aim is to co-design a web application prototype for the visualization of the gait-related issues. Through this web application neurologists can be informed about the progression of the patients' gait disturbances accurately. To reach this aim, a user-centred design process was used. Firstly, based on a literature search an initial prototype was created which then has been improved after conducting interviews with neurologists through various iterations. Afterwards, the prototype was appraised by visualization experts to eliminate any possible potential visual problems. Various interviews with neurologists and visualization experts evaluated and gauged the prototype from two different perspectives, which led to the development of the final prototype. The final prototype meets not only neurologists' requirements but also visualization experts' suggestions to reach a comprehensive design. As a result, the final prototype could provide accurate data for neurologists in order to assess various gait issues in Parkinson's disease.

Contents

CHAPTER 1

Introduction

1.1 Motivation and Problem Area

As population ages, Parkinson's disease (PD) has become more prevalent. PD is a progressive neurodegenerative disorder that can affect the quality of a patients' life due the numerous motor and nonmotor complications [1]. More than 10 Million people worldwide suffer from PD [2]. Although there is no cure for PD, rapidly diagnosing of it could be helpful to prevent the disease progression speed [3]. One of the common causes of disabilities in PD is gait disturbance, which should be evaluated during clinical assessment. Patients visit their neurologist regularly throughout the year in order to adapt their medication regime. When the medication is effective patients experience "On" phases and gain control over symptoms and their movement improves, however in the "Off" phases, the medication ceases to be effective and patients will face mobility issues. Therefore, adjusting the medication is of high importance in order to reduce the "Off"phases of PD. For modifying the prescription plan correctly, the symptoms should be evaluated carefully. Evaluating symptoms can be done during the clinical assessment of Parkinson's, where the patients and the neurologists gather together in order to evaluate the severity of the patient's symptoms [4, 5]. One way to subjectively assess PD during consultation time is scale based assessments, traditional patients report and simple examinations, which are not reliable enough [6]. On the one hand, it is difficult for patients to evaluate their symptoms and inform neurologists during the consultation about the progression of the condition. On the other hand, neurologists draw on a short observation during the consultation to decide how the person is going at the moment, which might not provide the most accurate picture. If neurologists could have more detailed information about patients' symptoms or tools for objectively tracking symptoms during patients' routine lives, they could make a better decision for effective treatment. Lack of accurately diagnosing the severity of symptoms during a consultation is considered a problem in this area, which could be solved by using technology.

1.2 Aim and Objectives

An objective system that could monitor the patients during their daily lives would be exceptionally helpful due to provide an objective understanding of different symptoms and disease progression. Fraunhofer AICOS [1] has developed an algorithm to constantly monitor gait parameters of Parkinson's patients in order to understand the severity of the gait disturbances. Patients can gather data passively via their smartphones during their day to day lives. By collecting data passively, the patients can provide information for neurologists to understand when medication is effective (On phase) and when the medication effect is over (Off phase). Therefore, patients will receive an accurate medication regime. So, visualization of the collected information could provide a better understanding of the progression of PD, gait parameters and Off and On phases for neurologists.
The aim of this work was to understand the factors which are paramount and decisive in diagnosing the gait-related issues and PD progression, and to notify the neurologists of these factors. So a user-centred prototype design to visualize these required factors was contrived. To reach this aim different steps were taken. Primarily, a literature search was conducted and studying similar research was done in order to formulate the first iteration of the prototype. Secondly, the initial prototype was presented in an interview with a neurologist to gather feedback. Then, the collected feedback was analyzed in order to adapt the prototype and create the second iteration. This process was continued by conducting further interviews with neurologists who were eager to participate in our research. Afterward, interviews with visualization experts were conducted, and the created prototype was evaluated from their perspective and the issues were accommodated in order to reach the final prototype. Thus, among routine clinical consultation, neurologists could be able to access each patient's account and could be informed about their gait disturbances and adjust medication accurately. It is noticeable, this system does not aim to replace the visit consultation and just provide more accurate data to be used during consultations. In other words, this visualization provides observation of the normal patient's movements during their day to day lives.

1.3 Methodological Approach

Since we aimed at investigating the web platform prototype for visualizing gait disabilities, our research was based on qualitative research methods. Therefore, we focused on users' needs throughout user-centred design process. In the first phase, we designed an initial prototype based on a literature search and then we conducted qualitative interviews as core elements. Then we analyzed the result of the interviews to further developments of the prototype in order to reach the final prototype. Chapter 3 provides a deeper insight into the methods used in this research.

[1] https://www.fraunhofer.pt/en/home.html

1.4 Key Contributions

The key contribution to this work is developing a prototype to visualize the gait disturbances of PD by integrating the knowledge of two different groups of participants, respectively neurologists and visualization experts. Evaluating the prototype from a neurologists' perspective helped our understanding of requirements needed to assess the disease progression. It also gave us more insight about their concerns regarding the prototype and challenges which they had during the utilization of the prototype . However, the evaluation of the visual aspect had a different focus. The focus was on finding the best possible solution to increase the usability of the prototype in the shortest time and to eliminate the challenges the neurologists faced during interacting with the prototype. Therefore, the final prototype could enable neurologists to track progression of PD, thus they could understand the "Off" and "On" phases of PD correctly and modify the medication accurately.

1.5 Structure of the Work

This master thesis is organised as follow:
Following this introduction, chapter 2 describes the background and related work, including the definition of PD, symptoms, treatments, subjective and objective assessment of PD and similar visualizations. Methodologies of this work are outlined in chapter 3. The implementation of the initial prototype and interview findings are presented in chapter 4 and chapter 5 respectively. The final prototype is implemented and evaluated in chapter 6 and discussion is outlined in chapter 7. In chapter 8, the thesis is concluded and opportunities for future work are proposed.

CHAPTER 2

Background and Related Work

This chapter introduces PD, symptom monitoring technologies, and information visualization. Starting with an overview of Parkinson's symptoms, diagnoses, treatments, and assessments of PD provide a broad introduction about the topic and problem statement. In the following, we described the current technologies for monitoring symptoms and various techniques for information visualization.

2.1 Parkinson's Disease

In 1817 for the first time, Parkinson's disease was medically described as a neurological syndrome by James Parkinson. He described PD as "involuntary tremulous motion, with lessened muscular power, in parts not in action and even when supported; with a propensity to bend the trunk forwards, and to pass from a walking to a running pace: the senses and intellects being uninjured" [7]. PD is a progressive neurological disorder. While the aetiology of is still under investigation [8], however, based on some research, the loss of nerve cells containing the neurotransmitter 'dopamine' in the brain, is suspected to be the cause. PD is considered as a chronic disease, which is a long-lasting disorder and the progression of it could be controllable, however, it is not curable [9]. Furthermore, it presents mostly in people over 60 years old, therefore it is an age-related disease [10]. PD is also named a movement disorder [2], which makes patients unable to complete their activities of daily living. Although it can affect their body movement, it has also some non-motor symptoms that unfortunately become worse with time [11]. The impact of symptoms on quality of patients' lives is highly substantial.

2.1.1 Symptoms

A patient will experience the first symptoms of PD when the remaining production of dopamine comes below 20% of its usual production or also when half of the cells of the substantia nigra have been ruined. PD has various motor and non-motor symptoms. Motor symptoms are those which disturb body movement, while non-motor symptoms are those which are not related to movement but also common and can cause a major impact on Parkinson's patients. Bradykinesia, rigidity, tremor, and postural instability belongs to motor symptoms and depression, sleep disorders and pain related to non-motor disorders. The following table represents some of these main motor and non-motor symptoms [12].

Motor Symptoms	Non-motor symptoms
Gait and freezing of gait (FOG)	Mood disorders like depression, anxiety and apathy
Tremor	Sleep disorders like sleep fragmentation, REM sleep disorders
Rigidity	Cognition like dementia and bradyphrenia
Bradykinesia	Autonomic disorders like sexual dysfunction and constipation
Postural instability	Breath
Handwriting	Blinking

Table 2.1: Motor and Non-motor symptoms of Parkinson's disease [12]

Motor Symptoms

As motor symptoms influence movement activities, the patients face problems in their routine activities such as walking, eating, drinking, etc. These symptoms will be emerging on one side of the body and by the progression of the disease over time, both sides of the body will be affected [13]. In the following section, some of these motor symptoms and also FOG are outlined.

Bradykinesia: This symptom is characterized by a decrease in the speed of the patients' movement. Bradykinesia might be seen even in depression, therefore, it is important to be distinguished from other diseases [14]. Akinesia and hypokinesia are two terms that are used synonymously with bradykinesia. Akinesia refers to a lack of spontaneous movement and hypokinesia refers to those activities, which not only become slower but also smaller than what they are supposed to be [15].

Tremor: Resting tremor shaking, called 'tremor', is an involuntary movement when the body is in the resting state. Arms, hands or legs shake in a 'rhythmic oscillatory' pattern [4].

Rigidity: Rigidity is classified by decreased flexibility and stretching of the muscles. Patients also struggle to display facial emotions and some facial changes occur, termed the 'masked face'. Furthermore, this symptom makes patients unable to turn their body during walking or sleeping [16].

Postural instability: As the disease progresses, this sign can appear. These symptoms can make the patients unable to maintain their balance and stability during their day to day life.

Freezing of gait: Freezing of gait is deemed as one of the most important factors that make Parkinson's patients disabled to walk. Therefore, it is related to motor symptoms [17]. Because this symptoms happens suddenly, a patient cannot continue his walking process for a while or even cannot start the initial steps. Despite patients being aware of this symptom while it appears, they cannot move for a while, because they have the feeling of sticking to the floor.

Non-Motor Symptoms

Although PD has been assumed a movement disorder, over the last two decades, the non-motor features play an important role in quality of life (QOL) of the patients. In the following point, some of these non-motor symptoms are highlighted in more details.

Cognition: In the late phase of PD, some cognitive problems such as issues with thinking and judgment, as well as sleeping difficulties, may develop [18].

Pain: Most Parkinson's patients experience body pain. Pain is associated with fluctuations in motor strength, muscle spasms or cramps, which are termed 'dystonia', or from musculoskeletal injury, likely related to their gait and imbalance issues [19].

Depression : In some cases, after diagnosing the disease the patient may become depressed. 10-45 percentage of Parkinson's patients confront with depression [20], which is characterized by sadness, feeling of guilt and remorse. Mild to moderate depression also can be emerge in all phases of the disease [21].

On/Off phases

Besides motor and non-motor symptoms, Parkinson's patients will experience "On" and "Off" phases. Parkinson's patients can experience a condition when the medications are not effective anymore and the patients become very stiff and even unable to move, termed Off phase. However, the On phase refers to a condition, which the medications are still effective, therefore patients feel energetic and able to move [22]. As in the advanced stage of PD patients can face fluctuations between On and Off phases, it is crucial to detect Off phases.

As we mentioned in the previous paragraphs, PD has a wide range of symptoms, nonetheless, the focus of our research is only on gait issues.

2.1.2 Diagnosis

As still there has not been any test to diagnose PD during life, the diagnosis is done by neurologists thorough neurological examinations [23]. Consequently, the diagnosis of the PD in the early stage is considered as a challenge due to the lack of a definitive test for diagnosis. Parkinson's symptoms and their severity vary from person to person, so it is highly important to detect the patients Off phases to modify the right medication regime. Otherwise, PD can be uncontrollable and patients will need more care. It is vital to measure the condition of the patients to modify the medication and reduce the side effects. Patients who suffer from PD should visit their neurologists to reassess their condition every 6-12 months or every 2-3 months to take a new medication plan [24] cited in [25]. Due to the lack of a direct test to detect the PD, the neurologists perform a neurological examination.

2.1.3 Treatment

As PD is not curable, the treatment is only aimed to improve the QOL of the patients. Levodopa is the most successful medication for PD patients and the severity of the symptoms can be reduced by taking it.

As the disease progression speed also varies among patients, some patients have a complicated medication regime. Thus, they must take more than one drug several times each day. Neurologists struggle to find a suitable medication regime for each patient, which works well for them and try to manage the condition effectively. The definition of treatment in PD refers to a decrease the Off phases and increases the On phases. Parkinson's patients usually after receiving a new medication regime are not hospitalized and go home and have their routine lives. Only in a few cases, when the neurologist diagnoses that implementation a deep brain stimulation could be helpful, patients will be hospitalized for surgery.

2.2 Subjective Assessment of Parkinson's Disease

As each patient experiences different symptoms of PD with various severity, measuring the symptoms especially in advanced levels of PD is challenging. Nowadays, in the clinical assessment of the PD the neurologists use clinical rating scales such as Unified PD Rating Scale (UPDRS) [26] and the 39-item PD Questionnaire (PDQ-39) [27].
These assessments are based on clinicians' observation and patients' reports. Among diverse scales for quantifying motor symptoms of PD, the Unified Parkinson's Disease Rating Scale (UPDRS) is well established [14]. The rigidity, tremor, and gait can be estimated via this universal test by a neurologist [28]. Based on Perlmutter [29], UPDRS consists of four sub-scales for assessment of behavioral problems(I), a patient's ability to carry out everyday tasks(II), motor skills of a patient(III), treatment complications, painful cramps, and irregular medication responses(IV). While part I, II and IV can be

evaluated by patients' reports and questionnaires, part III should be evaluated through performing physical examination.

2.3 Objective Assessment of Parkinson's Disease

As subjective assessment of PD is not accurate, nowadays, there is a growing tendency for an objective assessment and technology can dramatically change the PD assessment. IT-based systems provide a way for long term monitoring and they can capture the symptoms accurately. Therefore, monitoring the severity of motor symptoms can lead to better decision making and facilitate medication adjustment. Presently, there is a lot of research which aims to provide a tool to an assessment of Parkinson by monitoring the symptoms. Accordingly, there are several tools that can monitor Parkinson's patients' symptoms continuously during their routine lives.

2.3.1 Wearable Sensors

In recent years, a wide range of studies has been conducted to investigate the use of wearable sensors in assessing the symptoms of patients suffering from neurological disorders. Based on [30], various motor symptoms such as gait disturbances, freezing of gait, falls, bradykinesia, dyskinesias and tremor and also non-motor symptoms like sleep disturbances and autonomic dysfunctions can be monitored through wearables. Various sensors are implemented in wearable devices in order to capture and monitor symptoms. Sensors can be implemented either in devices or even be directly attached to the body. In the process of monitoring the symptoms, one sensor or combination of different sensors can be used. Wearable sensors have various types such as pressure and force sensors, inertial sensors, goniometers and ultrasonic sensors, electromyography sensors (EMG) [31]. Although wearable sensors can be used in laboratories or home environments, monitoring patients in laboratories environments has some drawbacks. The process of evaluating symptoms in laboratories is an expensive way to monitor and analyze symptoms. additionally, in laboratories patients might not behave like they do in their daily lives. According to Ferreira et al. [32] through home-based monitoring, the patients had more satisfaction. Due to patients' satisfaction, more wearable devices and smartphone applications are being designed to monitor patients in such type of environment.

Based on Bachlin et al. [33] a wearable assistant has been developed to detect the FOG. The system consists of on-body acceleration sensors to measure the patients' movement and also a small portable computer to record the data. Two 3-D acceleration should be attached to the patient's foot, one above the ankle and the other one above the knee. Aside from that, one more acceleration sensor is attached on the belt that is to be worn by the patient. The collected data can be transferred to a portable computer using wireless Bluetooth. Anytime the patient experiences the FOG, in addition to capturing the symptoms the assistant also prepares a rhythmic audio signal that stimulates the patient to continue the walking process.

Mazilu et al. [34] developed a wearable device called GaitAssist, with the same aim as Bachlin et al. [33] which can be used for either daily life assistant or as a support for gait-rehabilitation exercise. The aim of the GaitAssist device is also detecting the FOG episodes but it is more advanced in comparison to Bachlin et al. [33] due to using a smartphone instead of a portable computer and its android application. GaitAssist device is portable, light in weight and can be personalized by the users by adjusting the sound and so on. A rhythmic sound is adjusted on patient gait and can guide the patient to continue their gait based on the rhythm of sound. GaitAssist consists of two Inertial Measurement Units (IMU), which should be attached to the user's ankles and a smartphone, which will obtain collected data via Bluetooth. An android application installed on a smartphone also consists of two separate parts, (a) the Rehabilitation exercise module and (b) the FOG-detection module. A user can adjust them and receive feedback based on the selected module. Although GaitAssist has advantages, it has an unignorable drawback related to its battery life.

Mariani et al. [35] present an On-Shoe wearable device, for monitoring long-distance-walking and detecting the abnormal gait. Wearable shoes fused with range sensor arrays (WSFRSA) consists of various sensors such as four range sensors are located on the four different edges of each shoe and also six force sensors located on arch, heel, and forefoot. Each heel sensor is surrounded by three range sensors and the last remaining range sensor is located near the forefoot. Collected data by force sensors and initial sensors will be sent to a user computer located nearby with two WIFI modules which are located on each shoe. Gathered data by range sensors also will be transfered to the same PC by another WIFI module. As a drawback for this wearable device, we can point to its distance limit. The WIFI module should transfer gathered data to the user computer which is nearby him. Therefore, patients cannot use this device during their routine life.

Niazmand et al. [36] has developed a wearable smart pullover to record Parkinson's symptoms while the patient is executing the motor tasks. Eight numbers of acceleration sensors are attached in various areas of the pullover such as right and left upper arm, forearm, right and left of the trunk, stomach, and neck area. Moreover, an algorithm runs on a computer that can evaluate the data, which is received via wireless or connecting the SD-card. Feedback about the progression of the disease and the severity of symptoms will be presented on the computer.

2.3.2 Smartphone Applications

At present smartphones are very popular and people use them during their daily lives. They are inexpensive, ubiquitous and portable; therefore, they can be considered as an efficient way to monitor PD symptoms. Through the use of a smartphone's various motor and even non-motor symptoms can be measured. For instance, patients' audio and video can be recorded by smartphones to further analysis as well as their handwriting when they are writing on the smartphone screen. Besides, patients' mood can be captured by entering their diaries on their smartphones.

Apkinson is an android Mobile application, which paves the way to analyse the speech signal of a PD patient to be informed about the disease progression. PD can also affect the patients' speech by reducing their voice volume, monopitch, and voice quality. Therefore, this application records patients' speech and duration of a call conversation. So they can be compared to certain features to understand disease progression. If the patient's condition is getting worse, Apkinson can understand it from analysing the patient's daily conversation and will suggest a patient to visit a neurologist sooner than his predetermined appointment [37].

There are a few mobile applications for monitoring tremors. Some of these applications are not free, not downloadable from outside of the USA app store, and cannot be exported directly. For these reasons, Kubben et al. [38] provided a free open-source iOS mobile application named "TERMOR12" to monitor the tremor symptoms. This application provides a way to export all raw measurement data from offline analysis. There are also commercial products available to objective assessment of PD . In the following section, some are highlighted.

2.3.3 Commercial Products

Kinesia ONE [1] and Kinesia 360 [2] are two Parkinson's assessment tools that were produced by Great Lakes Neurotechnologies company. Both systems can track tremor, bradykinesia, dyskinesia, and mobility of the patient with Parkinson's (PWP). Patients will receive the Kinesia ONE with a complete kit, which provide the conditions for utilizing the device. The kit composes of an iPad mini with a pre-installed application, a sensor, and also a user manual. The sensor should be worn on the finger by the patients. Then it can assess symptoms during performing various tasks. The patients should interact with an iPad application using its touch screen to start the tests. The worn sensor will transfer the collected data through Bluetooth to the iPad. After completing each assessment, newly gathered data will transfer to the web portal. It is noticeable that the web portal complies with HIPAA to protect patients privacy. The patients progression can be measured either at home or even in clinical visits via using Kinesia ONE. Patients can also follow their motor symptoms daily using Kinesia ONE. Neurologists and researchers also can access to collect data on the web portal which is transmitted to the cloud via WiFi connection or broadband. Although Kinesia ONE and Kinesia 360 are similar, they have some differences. The Kinesia 360 consists of various sensors and a mobile application to track the Parkinson's patients continuously. It includes two sensor bands, one of which should be worn on the wrist and the other on the ankle. The patients can also report what they feel and their medication results by using the electronic diary of Kinesia 360.

Falling of a patient can be recognised by a device called Angel4 fall detector. The device consists of a small sensor that is placed on the waist using a clamping clip, or a comfortable specially designed belt. The device can be connected to the mobile phone or

[1] https://glneurotech.com/kinesia/products/kinesia-one/
[2] https://glneurotech.com/kinesia/products/kinesia-360/

a health center. In an emergency situation, the system can make a call and also send SMS containing information about patients' location [39].

All in all, monitoring patients activities can provide more accurate data for neurologists and facilitate decision-making regarding medication modification. But measuring patients' symptoms during patients' daily lives is considered a challenge. Due to this reason, many wearable and non-wearable devices have been developed. Amongst all other devices, utilizing smartphones are ,at present, the most effective way to monitor the patients' activities. Since users widely regard smartphones as a daily personal device, using it will not be bothersome for them. Also, by using smartphones, other wearable devices will not be necessary thus explaining the popularity of smartphone utilization for symptom monitoring [40].

Due to all the above-mentioned reasons, Fraunhofer AICOS has developed an algorithm to monitor gait issues in Parkinson's patients via smartphones [41]. Even though data is immensely valued, raw data is not intelligible. Thus, the data collected in accordance to the patient's symptoms should be visualized so that it is palpable to the neurologists. Visualization of medical information is exceedingly crucial because physicians could then rapidly perceive a wide range of clinical parameters to treat the patients. As chronic disease needs repetitive tests over the year, understanding and comparing the collected data might be difficult. Information visualization can address this problem and design graphic representation of data which paves the way for understanding the data elements and patterns easier. The dilemma of medical data , visualization is related to the amount, variety, and veracity of the data sets, and none of the data is straightforward [42]. Good visualization can provide accurate insight of the required data for neurologists; enabling them to find the patterns easier. As a result they could diagnose the disease progression with more accuracy. Due to this reasoning, in this work, a web-based platform prototype was designed to help neurologists during their consultation. In the following section, more information on similar visualizations are outlined.

2.4 Visualization

Information visualization is "the use of computer-supported, interactive, visual representation of abstract data to amplify cognition" [43] . In other words, combining the computer processing power with human perception and visual abilities, to understand and analyse the tasks is considered an aim of information visualization research [44]. Visualization of medical data is challenging. On the one hand, a lot of relevant information should be illustrated and on the other hand, the information displayed should be simple enough to be perceived effortlessly [45]. Nowadays there are a lot of efforts in the visualization of medical data. In the following segment, some of these visualizations are outlined.

In 1994, Powsner and Tufte proposed summarizing the patient status, test results and treatment data on a plotted graph. This was one of the earliest examples of using a diverse array of data-sets in medical records in order to visualize information [46].

Allot et al. [47] focused on developing a web platform; inspired by social networks in examining genetic disease. Social networks are organized around three components: genes, humans and genetic disease. Users' behaviour provides insight for understanding connections between different agents. Moreover, all genetic disorders and human genes are included in the network. In this work, various visualization technique has been used which are highlighted below: (1) word clouds is used to show the most specific ontology terms, (2) barcodes offer a synaptic and interactive view of the density of variations related to regions of a gene or effect on a protein, (3) highlighted words in text identifies the most pertinent paragraphs for a given human user, (4) networks of friends help to understand the connections between agents and identify groups of highly connected agents, (5) colors highlight modifications in textual information related to agents, (6) timelines show the evolution of the popularity of gene collaborators on a topic, (7) pairwise alignments identify the differences between two versions of a protein sequences, and (8) heat maps on schemas of the human body, brain, and fetus to allow easy analysis of the expression pattern of a given gene.

Cardoso et al. [48] has developed an interface for evaluating Amyotrophic Lateral Sclerosis disease by creating interactive charts. The chart visualization consists of colors which are also suitable for color-blind people. In addition, the user interface supports different languages such as English and Portuguese. Users can further customize their information to personalize their interface. For instance, various filters can be applied to charts, and the size is also adjustable. The user can select one of the offered color palettes and customize their interface even further.

Frink et al. [49] mentioned visualization tools design specifically for physicians which had web and mobile substructures. What they designed in particular had features such as: "Continuous Month" which was like a calendar and the color of this option varied depending on the average measured parameter. "Continuous Day" represents the hourly measured values through vertical bars "Circular Day" is a pie chart which is divided into 24 segments and each radial segment is a representation of an hour. This view allows the user to analyze each parameter individually, and similar to the "Continuous month" view, the color varies based on the mean value "Multi-Circular Day" is applied to study a parameter over the span of several days.

To sum up this chapter, literature search was vital in recognizing PD symptoms and different assessments of PD. Literature search showed that due to lack of accuracy of the clinical assessments of the PD, there is a growing tendency to utilize objective assessment of PD by a variety of means. Using smartphones as a monitoring device, due to their popularity and convenience, is very common nowadays. Due to the large volume of data, neurologists need a method of data collection that has a visual aspect and is easier to comprehend. Therefore, the importance of visualization cannot be overlooked. There are a lot of efforts in order to visualize data related to various diseases to abet the physicians in their consultations.

CHAPTER 3

Methodology

In the following chapter, the research methods which were applied for this work will be described. Figure 3.1 illustrates this research process to reach the thesis aim. As we conducted aUser-centred Design (UCD), the qualitative methods have been used. This chapter starts with a brief introduction of UCD.

3.1 User-Centred Design

The term UCD often used in the research of human-computer interaction, where the target group of a system can influence on the design process and the final design will be based on the target group requirements. "The term 'user-centred design' originated in Donald Norman's research laboratory at the University of California San Diego (UCSD) in the 1980s and became widely used after the publication of a co-authored book entitled: User-Centred System Design: New Perspectives on Human-Computer Interaction" [50] cited in [51].

> "But user-centred design emphasizes that the purpose of the system is to serve the user, not to use a specific technology, not to be an elegant piece of programming. The needs of the users should dominate the design of the interface and the needs of the interface should dominate the design of the rest of the system" [50].

UCD is a process of iterative design, in which end-users have the main influence on the design process. Among UCD, all the users' needs and requirements should be fulfilled in order to provide a powerful system [51]. In this work, an iterative design process was conducted and neurologists as the end-users of the system had a significant effect on each level of the design process to reach the final intended design. The requirements for the first iteration of the web prototype were derived from the literature search, while

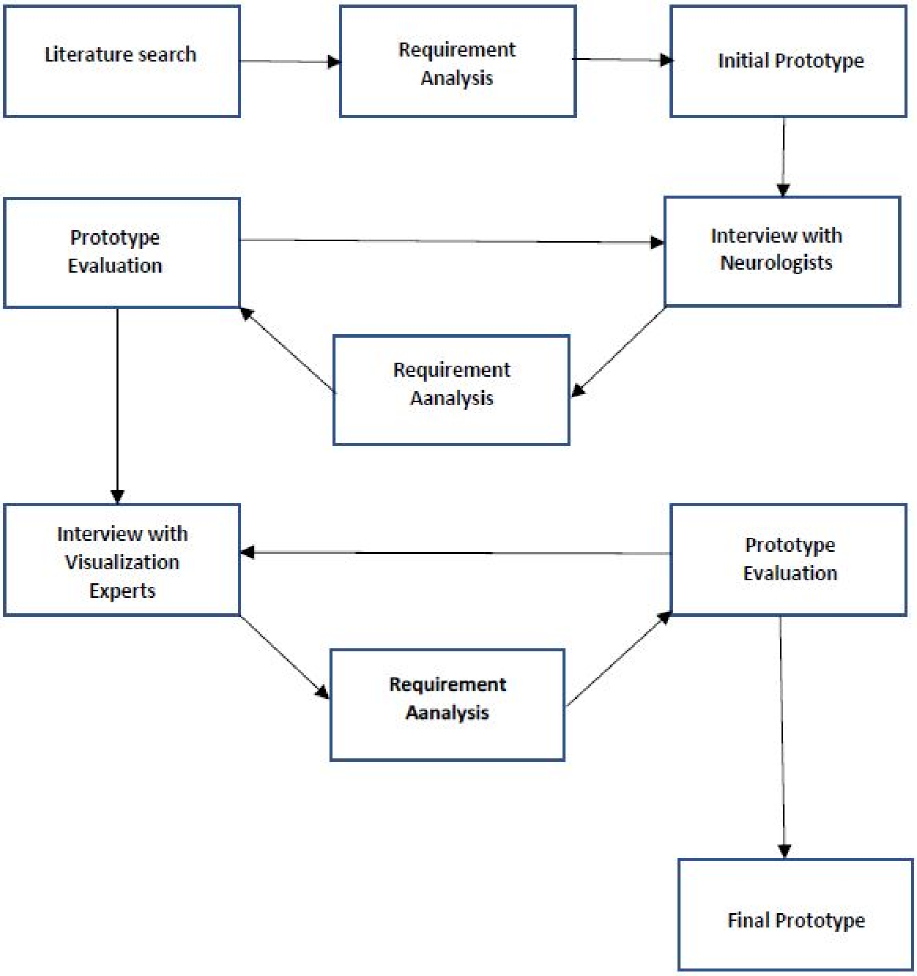

Figure 3.1: Steps of planned methodological approach

in the subsequent iterations, the requirements were gathered based on analysis of each interview.

3.2 Literature Search

A literature search was conducted to cover all of the theoretical aspects which were relevant to this research and could be helpful to reach the research aim. To get an overview of PD a broad range of literature according to PD, symptoms, subjective and objective assessments of PD and treatments were studied. Furthermore, we focused on the effect of PD especially on patients' gait and also related work and current technologies for monitoring Parkinson's patients' activities were studied. By doing this research we got familiar with other technologies and its pros and cons. For a literature search, different sources such as ACM [1], Google Scholar [2]and Wiley [3] were used. The literature is revisited for the final analysing and conclusion.

3.3 Interviews

The interview method is a well-known proven research tool used to gain information about specific topics in more detail [52]. In this work, several interviews with two different groups of participants, namely neurologists and visualization experts, were conducted. Therefore, various insights could be gained not only from the neurologists' perspective, but also from the visualization experts' perspective.

Interviews are divided into three categories: structured, unstructured, semi-structured [53]. A structured Interview entails a prepared list of questions which are asked in a specific order during the interview phase. Conversely, in unstructured interviews, questions are not prepared beforehand. In this specific case, both semi-structured interviews and unstructured interviews were conducted, the former with neurologists and the latter with visualization experts. The following paragraphs offer more insight regarding the methodology and process.

3.3.1 Recruitment of Medical Specialists

We involved medical specialists in the design process of the research project's web platform, in order to get an idea about the important factors to evaluate gait issues and their points of view about each iteration of the prototype. Finding interviewees who have not only time, but also interest in participating in the research study presented some difficulties. Although various attempts of reaching out to potential candidates were made, such as writing emails or arranging visits to neurological institutes, for instance the neurological institute of the Vienna General Hospital [4], unfortunately a significant number of participants who would be willing to participate in the project were lacking. Most of the neurologists were not willing to participate in our research, due to their strict schedule, while some rejected our request due to personal reasons. After contacting some private neurology consultants, just one of them accepted to participate in our research project. As we needed more interviewees, fortunately some neurologists hailing from Spain and Portugal, who had already participated in similar research and were interested in this topic, were introduced by Dr. Nunes to us. Each of the candidates were contacted and appointments were set up in accordance with their availability. After each Interview, each interviewee was asked if he/she knew other neurologists or medical students who would have information, time, and interest to participate in our research. As a result, we found two more neurologists who were interested in participating in our research.

[1] https://dl.acm.org
[2] https://scholar.google.com/
[3] https://onlinelibrary.wiley.com/
[4] https://www.akhwien.at/

Of the seven neurologists, six interviews were conducted via Skype [5] and one in person Austria, lasting between 30-60 minutes. Table 5.2 shows the participants, their years of experience, location and prototype version presented in interview. Due to protection of the participants' privacy [54], their real names were omitted, and replaced with codes.

Name	Gender	Age	Years of experience	Country	Prototype
N1	Female	52	22	Spain	First iteration
N2	Male	40	13	Spain	First iteration
N3	Female	55	20	Austria	Second iteration
N4	Female	65	35	Spain	Second iteration
N5	Female	30	6	Spain	Third iteration
N6	Male	28	2	Spain	Third iteration
N7	Male	40	13	Portugal	Fourth iteration

Table 3.1: List of neurologists with gender, age, years of experience, location and prototype version presented in interview.

[5] https://www.skype.com/en/

As it was decided to conduct a semi-structured interview, it was deemed necessary to establish certain guidelines to which could be adhered during the process. The guidelines form a central part of the semi-structured interviews and consist of several questions. Table 5.2 displays some of these core questions that are asked during interviews. The intention was to cover a broad range of the subject area according to the corresponding interview topic. The complete interview guidelines is available in the appendix B. These question types were defined according to [55]. However, during the interview some questions were changed, and some were added based on information that we gained from the interview. The overall guideline structure and principle questions were the same in all interviews. With the interviewees' full agreement, audio files of the interview were recorded. To prevent technical problems, all interviews were recorded by two different smartphones. If the audio recording was not feasible, notes were written during interviews.

Type	**Question**
Grand Tour	Could you describe me the last consultation you had with a Parkinson's patient?
Grand Tour	Imagining that you would like to monitor the gait of the patients, what would be the most important metrics to record?
Example Questions	Can you give me some examples of successful technologies to support clinical decision making? What makes them good examples?
Experience Questions	Do you have any experience about using a web platform, which could visualize Parkinson's Patients symptoms during their daily life? If yes, what kind of negative and Positive experiences you have?

Table 3.2: List of core questions asked during interview

3.3.2 Recruitment of Visualization Experts

After deep understanding of neurologists needs and evaluation of the various iterations of the prototype, we conducted some more interviews with visualization experts to evaluate the prototype from their point of view. Due to their feedback we could improve the prototype to reach the final version. Conducting various Interviews with two different groups caused evaluation of the prototype from different perspectives. The recruitment criteria was choosing someone who had not only been interested in participating in our research but also had experience in visualization and human-computer interaction field. Therefore, we wrote an email to some visualization experts who are working at TU Wien and one of them accepted to participate in our research. After agreeing on time and place, this interview took place at the expert office at the TU Wien. The interview was performed in a neutral position to reduce the possibility of potential impact on the interviewee. After interview analysis and evaluation of the prototype, we realized that improvement of the prototype can be made by means of conducting more interviews with visualization experts. As we needed more experts in order to evaluate the prototype, we asked Dr.Nunes about the possibility of finding and introducing some more interviewees to us. Two more participants were introduced by Dr.Nunes who were both based in Portugal. Due to distance, these two Interviews were conducted per Skype. This interview was a bit different from the first one due to simultan conduction of both interviews. The predesigned prototype was illustrated and both interviewees expressed their feedback. Moreover, Dr.Nunes also participated in this interview as a listener. In some cases through the interview, representing the prototype to the interviewee via Skype was not straightforward and therefore Dr.Nunes who was siting next to one of the interviewees, tried in some cases to clarify incomprehensible parts. After conducting the two interviews, the prototype was evaluated and changed. However, some points were still questionable afterwards. So, we decided to conduct more interviews. As one of our last interviewees showed interest in this topic and participated in our research, we asked him again to participate in the second interview. All these interviewees with visualization experts were recorded in order to be transcribed. As we performed unstructured interviews, we did not prepare any guidelines and just the prototype was evaluated by them. During all interviews there were some notes written to be able to provide a way of referring to something without interrupting the interviewee. After conducting each interview, the transcription was written and the analysis was made.

Name	Gender	Years of experience	Country	Prototype
E1	Male	6	Austria	Fourth Iteration
E2	Male	12	Portugal	Fifth Iteration
E3	Female	12	Portugal	Fifth Iteration

Table 3.3: List of visualization experts with gender, age, years of experience, location and prototype version presented in interview.

3.3.3 Data for Visualization

For visualizations purposes, data regarding gait disturbances was required. Two datasets were provided by Fraunhofer AICOS for this work. The initial prototype was created by the data collected from a healthy person. Subsequently, an actual PD sufferer was monitored using this system, per the request of Fraunhofer AICOS, for further research. Thus the final prototype was visualized using the real data provided by actual patients. More information about both versions of data are written in respective sections 4.2 and 6.1.

3.3.4 Ethics

The ethical aspects play an important role when human subjects are involved in the research. Based on [56] aspects such as being informed, consent, the ability to withdraw and anonymity need to be considered in an ethical framework. Therefore, informed consent was prepared and sent to each interviewee before conducting the interview and the to patient, before using the device. In this informed consent, we tried to give them general information about the research and make their roles in the research transparent. We mentioned that they can withdraw from participating any time with no consequences. We ensured them about their anonymity and mentioned that collected data is confidential and shall only be used by the researchers towards the originally intended ends. Furthermore, we informed them about the audio recording of the conversation and asked them to sign the consent stating that they agree with all the above conditions. In the appendix of this work, the consent form for neurologists, visualization experts, and patients can be found (see Appendix A).

3.3.5 Data Analysis

Thematic analysis is a known method for qualitative analysis of the data. Therefore, after conducting each interview, the whole interview was transcribed. We used all the audio transcribed and all notes which were written during the Interview as the analysis data. For transcribing the interviews an open-source tool called Otranscribe [6] was utilized. According to [57] there are different steps for performing a good thematic analysis. In the first step the researchers need to read the transcribed data several times and then write down their initial interpretations. After this step, the data should be coded. Next step would be arranging all similar generated codes in a theme. Some of the themes can have sub themes and some codes can be considered as separate themes. In the next step, all the defined themes and the whole text should be reread to make sure that there is not any uncoded text which could belong to one theme. The subsequent step is "define the essence that each theme is about". Then the final report can be prepared. For analysing the Interviews Atlas.ti [7] software, which is a tool for qualitative research was used. The transcript was structured by finding some codes in order to find specific patterns. Figure 3.2 illustrates a screenshot relating to coding of an interview which is done in Atlas.ti.

[6] https://otranscribe.com/
[7] https://atlasti.com/

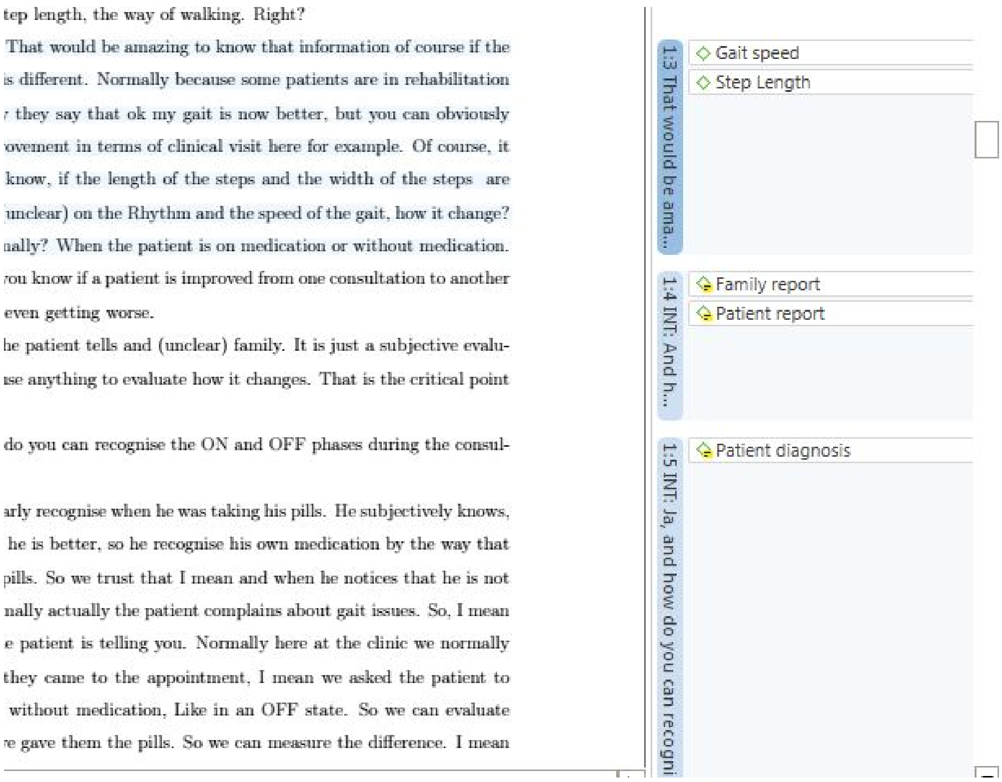

Figure 3.2: A screenshot of an interview which is coded in Atlas.ti.

CHAPTER 4

Initial Prototype

The iteration process was initially started based on analysis regarding similar literature and technologies. The literature search was conducted to understand important factors in gait evaluation, and to become familiar with the preceding research conducted to monitor Parkinson's symptoms. Besides, similar visualization were studied and utilized to help optimize human understanding. All gathered information was described in the background section.
The initial prototype was represented and evaluated during the first test-run with a neurologist as a professional in the field. In this research every iteration in optimizing the prototype was fully programmed so that it would allow the users to face a more realistic prototype and to interact with it. Prototype iterations can be found attached to the appendix C of this work. This section describes the first iteration of the prototype, data collection, and used technologies to create it.

4.1 Requirements

Providing each tool or software was premeditated and had a specific purpose. Medical specialists, who are the primary target group of this research could use this platform to obtain information about gait disturbances of their Parkinson's patients. Therefore, at the outset, the type of gait disturbances in PD based on literature review were sought out. Relevant data collected from the literature search substantiated that step length, gait speed, and the number of steps is paramount in order to evaluate PD progression. Step length reduction is one of the major and eminent variables in the evaluation of PD [58]. Due to the diminution of step length, patients face poor coordination [59]. Another factor, gait speed, is also deemed as a clinically crucial sign [60]. Hence during consultations, neurologists ask patients to walk the specific distance with their comfortable walking speed in order to analyse their gait speed. So, it was decided that step length, gait speed and number of steps were required factors in evaluating the disease's progression.

In “Off” phases of PD, the patients experience changes in their movements, hence their daily activities can be affected. Thus, the average of different activities of patients in different periods- hourly and monthly- were considered as a factor which should be visualized.

Then, it was decided to choose a visualization technique to visualize the requirements. Over the last decade, a wide range of visualization techniques have been developed. Selecting an appreciate approach should be based on the data structure and characteristics. The chosen visualization depends on the type of data (abstract, spatial), time (linear, cyclic) and visualization type (static, dynamic, 2D, 3D) [61].
Line plot is a good method for representing the time-related data and to visualize the relation between various time points. Thus, the initial prototype was visualized based on this technique. After gathering the requirements and selecting the visualization technique, implementation of the first prototype was started, which is described in the following segments.

4.2 Data for Visualization

Patient information, including their activities, and symptoms collected via the patients' smartphones was needed for programming and creating the prototype. In the initial prototype as well as some of the further iterations, real data collected from Parkinson's patients were not available. Consequently, available data were collected by a healthy person passively for an approximate period of 19 months from 06.08.2017 until 06.03.2019. We received the data by Fraunhofer AICOS which was extracted as an Excel file.
The data collected comprised various activities such as walking, running, sitting, standing and lying, etc; and were gathered every hour. Figure 4.1 represents a screenshot of the exported Excel data. Some of the collected information was outside the scope of our work, so the only information taken into account were the factors necessary for neurologists in order to evaluate patient gait issues such as stride length, gait speed, number of steps and average of each activity. In collected data file, some abbreviations such as E, T, D, S is written next to each activity. Below is mentioned what each word is abbreviated.

D= Distance
E= Energy
T= Time
S= Steps

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Date	TypeID	LookPhor	NoUseT	NoUseE	TiltT	TiltE	WalkT	WalkE	WalkS	WalkD	RunT	RunE	RunS	RunD	SitT	StandT	LayT	Moderate	Vigorous	timestam
2017/8/6 at 12:0	Hourly	-	10000	0,224583	285000	21,45804	3305000	149,3793	4726	2798,449	-	-	-	-	-	-	-	265	0	1,5E+12
2017/8/6 at 13:0	Hourly	5,109269	15000	0,336875	2090000	152,7942	290000	14,43008	389	236,911	-	-	-	-	-	-	1030000	1455	0	1,5E+12
2017/8/6 at 14:0	Hourly	18,83129	1330000	29,86952	415000	29,74483	10000	0,60069	15	9,036081	-	-	-	-	-	355000	845000	280	0	1,5E+12
2017/8/6 at 15:0	Hourly	-	3540000	79,50257	60000	1,480718	-	-	-	-	-	-	-	-	-	-	-	0	0	1,5E+12
2017/8/6 at 16:0	Hourly	-	3585000	80,51318	15000	0,336875	-	-	-	-	-	-	-	-	-	-	-	0	0	1,5E+12
2017/8/6 at 17:0	Hourly	-	3395000	76,24618	25000	0,6546	-	-	-	-	-	-	-	-	-	-	180000	0	0	1,5E+12
2017/8/6 at 18:0	Hourly	-	155000	3,481041	620000	44,64864	45000	2,484555	57	34,69948	-	-	-	-	-	1560000	1220000	390	0	1,5E+12
2017/8/6 at 19:0	Hourly	-	235000	5,277709	740000	57,16314	-	-	-	-	-	-	-	-	-	-	2625000	540	0	1,5E+12
2017/8/6 at 20:0	Hourly	-	370000	8,309587	1135000	78,23678	165000	9,421148	222	135,7197	-	-	-	-	-	-	1930000	645	0	1,5E+12
2017/8/6 at 21:0	Hourly	-	425000	9,544791	1200000	88,40495	170000	9,496903	222	134,1101	-	-	-	-	-	-	1805000	805	0	1,5E+12
2017/8/6 at 22:0	Hourly	-	270000	6,063751	560000	30,46148	2420000	92,59232	3475	2060,238	-	-	-	-	-	-	350000	225	0	1,5E+12
2017/8/6 at 23:0	Hourly	-	780000	17,51748	610000	35,45946	2025000	86,60825	2875	1743,067	-	-	-	-	-	70000	115000	300	0	1,5E+12
2017/8/7 at 0:0	Hourly	-	3500000	78,60426	-	-	-	-	-	-	-	-	-	-	-	110000	-	0	0	1,5E+12
2017/8/7 at 1:0	Hourly	-	3550000	79,72715	-	-	-	-	-	-	-	-	-	-	-	55000	-	0	0	1,5E+12
2017/8/7 at 2:0	Hourly	-	3560000	79,95173	-	-	-	-	-	-	-	-	-	-	-	65000	-	0	0	1,5E+12
2017/8/7 at 3:0	Hourly	0,875875	1495000	33,57516	-	-	-	-	-	-	-	-	-	-	-	40000	2040000	0	0	1,5E+12
2017/8/7 at 4:0	Hourly	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3600000	0	0	1,5E+12
2017/8/7 at 5:0	Hourly	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3600000	0	0	1,5E+12
2017/8/7 at 6:0	Hourly	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3600000	0	0	1,5E+12
2017/8/7 at 7:0	Hourly	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3600000	0	0	1,5E+12
2017/8/7 at 8:0	Hourly	-	-	-	10000	0,492233	-	-	-	-	-	-	-	-	-	-	3590000	0	0	1,5E+12
2017/8/7 at 9:0	Hourly	1,313812	105000	2,358125	1615000	110,8992	1210000	74,393	1783	1140,006	-	-	-	-	-	10000	605000	1025	0	1,5E+12
2017/8/7 at 10:0	Hourly	1,459792	15000	0,336875	1300000	85,41984	430000	28,55892	642	463,015	5000	0,725404	10	10	-	15000	1720000	800	5	1,5E+12
2017/8/7 at 11:0	Hourly	1,167833	2125000	47,72411	765000	44,72599	195000	12,08772	277	186,4145	-	-	-	-	-	2005000	1610000	295	0	1,5E+12
2017/8/7 at 12:0	Hourly	-	-	-	535000	29,25484	495000	32,38657	751	519,6528	60000	8,7788	124	120,5901	-	2515000	-	300	60	1,5E+12
2017/8/7 at 13:0	Hourly	-	10000	0,224583	350000	19,27826	490000	29,39486	661	441,7046	-	-	-	-	-	2730000	-	145	0	1,5E+12
2017/8/7 at 14:0	Hourly	-	195000	4,379374	290000	15,39091	195000	12,73341	297	204,0314	10000	1,450808	21	20	-	2890000	-	95	10	1,5E+12
2017/8/7 at 15:0	Hourly	-	260000	5,839168	200000	9,890658	360000	23,47947	540	375,8994	-	-	-	-	-	2780000	-	185	0	1,5E+12
2017/8/7 at 16:0	Hourly	-	25000	0,561458	245000	11,83154	105000	7,084105	165	116,0743	-	-	-	-	-	3225000	-	80	0	1,5E+12
2017/8/7 at 17:0	Hourly	-	80000	1,796667	105000	4,705013	110000	6,86818	155	106,5066	-	-	-	-	-	3305000	-	35	0	1,5E+12
2017/8/7 at 18:0	Hourly	-	20000	0,449167	500000	31,15345	290000	18,71189	430	297,2933	5000	0,725404	11	10	-	2775000	-	310	5	1,5E+12
2017/8/7 at 19:0	Hourly	0,875875	5000	0,112292	685000	40,70845	445000	25,41699	547	366,2624	10000	1,450808	19	20	-	1705000	710000	210	10	1,5E+12
2017/8/7 at 20:0	Hourly	0,875875	20000	0,449167	105000	5,23036	150000	7,88909	157	104,949	-	-	-	-	-	1400000	1885000	5	0	1,5E+12

Figure 4.1: Collected data by a healthy person via smartphone exported in Excel

4.3 Used Technologies

To perform the same visualization content on different devices the Hypertext Markup Language (HTML) and Cascading Style Sheets (CSS) were used. In addition, the client-side code was written in JavaScript. Visualization of charts and diagrams were created using an open-source graphing library called Ploty JavaScript [1] which provides a way to create interactive plots which are fully customizable. Used Technologies will be presented in more detail in the following chapter.

4.4 Implementation

After determining the most important factors, we have developed the first iteration of the prototype in order to visualize these factors. Time and temporal data are highly imperative to our visualization since the disease progresses and the health status of the patient varies as time advances. Since neurologists need to modify the medication, we decided to visualize the data hourly to help them to understand the exact time when the medication's effect subsides. Line graphs are the common method utilized for visualizing the given data; thus that was the method used in the first iteration [61].

The first iteration consisted of one web page where the five important factors mentioned above, such as stride length, number of steps, gait speed, the monthly average, and the hourly average of different activities, were visualized. Figure 4.2 displays the "Number of Steps" diagram that compares the number of steps taken by the patient in 3 different individual months to provide a way for neurologists to compare intended factors among different months. The X-Axis illustrates the daily hours while the Y-Axis demonstrates the number of steps (m). For easier understanding, the line graph pertaining to each month is shown in different colors. The color corresponding to each month is displayed next to the diagram and by deselecting it, the corresponding line graph can be removed from the diagram (See Figure 4.3). Figure 4.4 and 4.5 depict "Step Length" and "Gait Speed" respectively, which follow the same pattern as the "Number of Steps" diagram. Figure 4.6 indicates the average percentage of various activities of the patient such as walking, laying down, standing, running, tilting, and no data (no activity) in various months. The "No Data" segment indicates the times when the patient did not use their smartphone- may it be due to running out of battery or not carrying their smartphone- therefore no information was collected by the system. Figure 4.7 represents the hourly average percentage of various activities of a patient for one month. Like all other charts, by clicking on any type of activity from the legend, that activity can be removed from the chart.

[1]https://plot.ly/javascript/

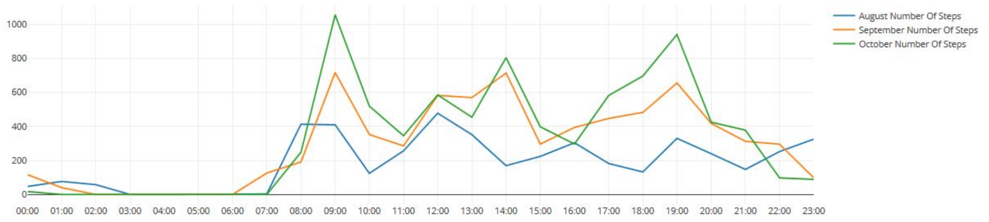

Figure 4.2: Visualization of hourly average of number of steps in 3 different individual month

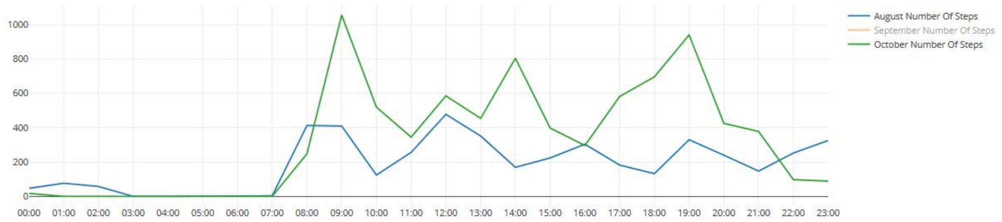

Figure 4.3: Visualization of hourly average number of steps while data according to September is deselected

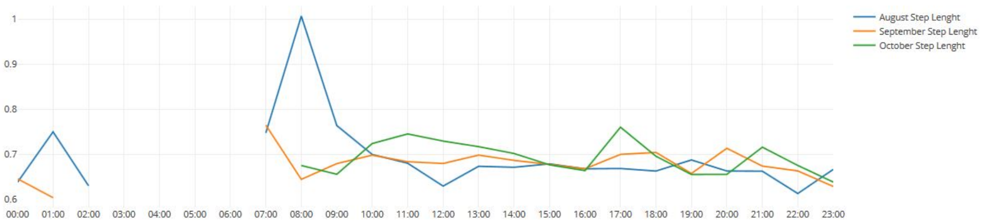

Figure 4.4: Visualization of hourly average of step length in 3 different month

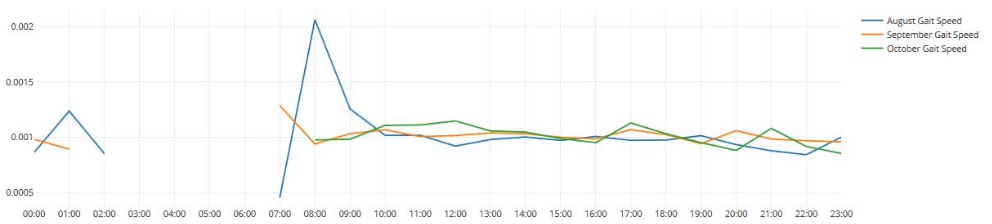

Figure 4.5: Visualization of hourly average of gait speed in 3 different month

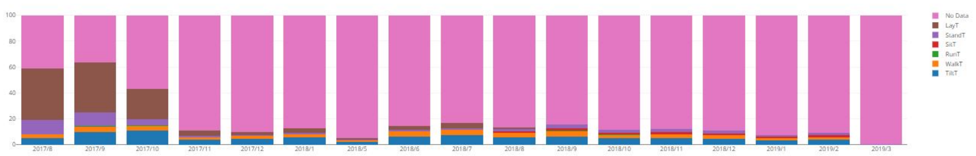

Figure 4.6: Visualization of monthly average percentage of various activities

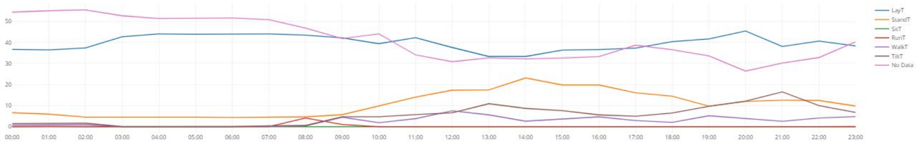

Figure 4.7: Visualization of hourly average percentage of various activities

CHAPTER 5

Interview Findings

Collecting users' needs is a vital step in developing any product and fulfilling these needs throughout the design process is essential to achieve a final prototype that provides an adequate user experience. The data obtained from the analysis of each interview has been used as a basis for further development of the prototype and the next interview. The main focus of the interviews with neurologists was to determine if the prototype included all the essential factors needed for their diagnosis and was user-friendly. The main focus of interviewing visualization experts was regarding interface and interaction design. After analysing each interview, the prototype modifications were implemented and the outline for the next interview would commence. In this chapter the result of all interviews with neurologists and visualization experts are discussed. For this purpose, all interviews were analysed thematically. It is noticeable that all of the neurologists requirements and visualization experts' suggestions were not implemented due to lack of possibility of implementation.
As it is described below, different iterations of the prototype were presented to different neurologists and visualization experts and based on the gathered information, the final prototype was established. All other iterations to reach the final prototype can be found in the appendix in detail.

Experts	Prototype Version	Appendix
N1 and N2	First Iteration	C.1
N3 and N4	Second Iteration	C.2
N5 and N6	Third Iteration	C.3
N7 and E1	Fourth Iteration	C.4
E2 and E3	Fifth Iteration	C.5

Table 5.1: List of the prototype iteration each interviewee was interviewed with.

As previously discussed in the prior chapter, the first iteration of the prototype was created only based on literature search. This iteration was presented to the neurologists N1 and N2 in order to collect their feedback. Subsequently, based on all collected information gained from interviews, the final prototype was developed. In the following segment, a summary of all neurologist feedback are highlighted.

5.1 Findings from Interviews with Neurologists

All neurologists agreed that stride length, gait speed, number of falls and freezing of gait are imperative factors in evaluating PD progression. Neurologist N2 stated : *"Number of falls, freezing of gait, gait speed is informative to me as well stability and the posture of the patients"*and Neurologist N5 noted: *"I think probably the issue is to know when the patient is walking. If their walk is normal. Like is all the time the patient is walking, how the variation of the gait is. Maybe in the Morning, the gait is lower than in the afternoon. Or maybe he has some disparities if he is at home, or if he is outside. Because it tells you about how the gait is changing during the day. Probably I think it is one important issue and then when the patient complains about their gait freezing, I think it is important to know how long those episodes are. [...] Of course, it would be good to know, if the length of the steps and the width of the steps has been changed".*

Neurologists N2 and N7 suggested that the prototype should include a normative value in order to compare a Parkinson's patient gait variation with gait variation of a healthy person. Neurologist N2 maintained: *"It is important if you can compare to normative values. So you can detect deviations for normative healthy values and the other values like step activities step length".* Also neurologist N7 stated: *"I think it is easy to understand. But I think we should have another line which would be the average of healthy control with the same age,gender and hight of the patient. Normal with normality it must be the same gender and the same age".*

Neurologists N1 and N2 believed the prototype could become more exhaustive if the time the PD patients took their medication was also included. They also suggested to highlight the activities or the reason not to do a certain activity. Neurologist N1 noted :*"It is more meaningful to me if context is added. When this diagram shows that the patient is sitting, the patient does not move because he cannot or he is watching TV, I do not know"* and neurologist N2 also noted: *"Monthly average activities. It depends as well , what are these activities important? I want to see when they are walking , when they are active . It is going to be important in terms of clinical information I don't know because it might be that person. I know the patients in the morning have their routine to be at home. Might be a person is enough making activity in the morning so that context might help. Perhaps some flags.flagging the patients might help. At least label when they take medication".*

One of the most important feedback gained from the neurologists was regarding information visualization of time intervals. Based on the collected feedback, not only monthly visualization of symptoms, but also weekly-even daily- visualization of factors are required.

Neurologist N3 noted : *"So you get a more realistic approximation of what is going on in his daily life by weekly and daily visualization"*. Also, neurologist N4 stated : *"Sometimes, there is a change of medication and I am looking for a side effect and it is interesting to know the data at different times. But in general, I think it is much more interesting to know the summary of one month. The patient would change by the week. Maybe all the diagrams, week by week, and then summary by month"*.
Moreover, neurologists N5 noted: *"I think it will be interesting to get that information, maybe just not for one month but per week. Because you need more accurate data. More accurate information about the motor symptoms of the patient. So, I think it would be more informative in terms of management and treatment, monitoring. For example to have that information but in a smaller amount of time. Just per week for example"*.
Besides, neurologist N6 stated : *"Most of the patients are stable and you do not want to see how he is going week by week. And if you have a button just to show you monthly it would be easier. But if you are changing the medication and you need to know how the gait has been changing during the first weeks, you probably need to know exactly how it is changing based a week"*.

Besides monthly and weekly visualization of data, providing a way to compare data with previous visits or any other time period is considered as an important feature of the prototype. Neurologist N2 mentioned : *"I would say probably one thing that might be as well important is also easy to compare with previous visits"*. While neurologist N5 noted : *"Imagine the patient tells you whether he is stable or not, imagine he tells you like in November he fell like many many times. So you should check what went wrong that month and you probably want to see how those weeks were during that time and what happened whether or not the patient took their medication and enabled them to compare it with other times"*.

Among all neurologists, neurologists N1 and N3 believed that they prefer to use a traditional method due to their general mistrust of the newer systems and the fact that they considered it to be more time-consuming. The Neurologist N3 believed that these kinds of systems are not usable for her generation and neurologists who are younger can use these systems. She believed that it is easier to ask patients about their symptoms by utilizing normal questionnaires instead of using the new technology to gather information about patients' activities : *"I think, in my generation, doctors would prefer to use traditional ways to recognise disease progression and this system would be acceptable by younger neurologists. I think so"*.
Neurologist N1 had also a similar opinion and claimed that the tool was too arduous for her to trust the data as she was more confident in verbally consulting her patients herself: *"I am not completely confident, I don't know the accuracy of the data. So before doing that I would like to see, I prefer to visit the patients"*.

Besides all neurologists' requirements mentioned above, they had some concern about monitoring the symptoms with smartphones and evaluation of the PD based on visualized data. Based on their feedback, lack of having smartphones, the position of smartphones, and the battery of it are challenging. Neurologists N1 noted: *"[...]Very elderly patients I* *am not completely confident if they will have a smartphone".* Also, neurologist N6 stated: *"I do not see any issue in that system. What I see is the most problematic thing would be that most Parkinson's patients are old people and they do not use a smartphone at least in Spain".* Neurologist N2 believed: *"The position, where you place it is challenging. It depends on where you locate it. If you are getting information in one way or the other.[...]Also battery of smartphones is a challenge".*

Additionally, time issues and lack of trust in these kinds of evaluation systems are considered as a next challenge. Neurologist N2 stated: *"Obviously time, usually we have very limited time, so it has to be very simple, easy to use, easy to access. Log in is very annoying. Because you have to keep security you have to some time logins are time-consuming"* and Neurologist N5 believed: *"The negative aspect would be you need to trust what the patient is telling you on the platform".*

However, the neurologists mentioned the advantages of the visualization platform are not ignorable. Based on neurologist N6 feedback, the system could provide better treatment for patients. *"Probably the treatments of patients would be better because we could monitor how he is at home and increase the medication. That would be much better".* Also, neurologist N5 stated: *"I mean, if you know that a patient has some changes when the motor symptoms appear because they are fluctuating.[...]So it allows you more accurate regulation of treatment. It allows a better understanding of, better motor control of the patient".*

5.2 Findings from Interview with Visualization Experts

After conducting all interviews with neurologists, for subsequent iterations, interviews with visualization experts were performed. Among interviews with visualization experts, the prototype has been changed significantly to reach the final prototype. In the following segment, all their feedback is outlined.

Based on expert E1 feedback, the visualization technique in order to visualize the data was evaluated. Expert N1 said : *"People prefer pie charts even though they might not be as accurate. [...] all diagrams could just simply have for instance bar charts and also line graphs".*

Expert E1 also mentioned the structure of the visualization was paramount and as medical data was being evaluated, users needed to be able to access data in the easiest manner and with the least time-consumption. Therefore, he suggested creating a structure in which an overview of all notable data are apparent at first glance . That way the users could understand which data is relevant to them and can get more meticulous regarding a specific piece of data on another page: *"If you have monthly data, you can do it like this (Point to what he drew) and then you can even provide a further overview to give them the weeks with these months. For instance, you could stick to this overview. Here you have it with August you can aggregate it up to all of the falls in August and you do that for every month and then you will have exactly the same diagram just not per hour* *but per month. Then they would say all right, so there were a lot of falls, there were a lot of falls and there were a lot of falls. So, this might be interesting for me to look at. This way is much faster".*

Also based on expert E2 feedback, the position of each chart and component is highly important. Expert E2 noted : *"What I would suggest is instead of putting these options next to the graph, maybe put them on top. Because if you put them next to each other you are saying this will affect this and if you put it on top it says that if you select here, it will change everything to downwards. Understand what I am trying to say? You are creating a relationship between one and the other. What you are saying to me is that if you change some selections here the whole graph can be a different graph". "This needs to be in a different position. Because as it is on the left side within this box, this suggests that these two graphs here on the right, will not change and just overlaying information on top of that".*

Implementation of heading for each chart on all pages are crucial and can be helpful to understand the charts. As expert E1 noted: *"Do not forget to add heading for all charts on all pages. It is important to know the heading to understand the charts faster".*

Expert E2 also mentioned that breadcrumbs are important in visualization and can be helpful for the users to know at any time what page they are on and what information they are following so as not to be confused: *"I would even say perhaps keep that type of breadcrumbs visible at all times. As long as people start clicking different options and going deeper into the visualization and the option selected. They can keep an overview of what the options that they chose initially".*

Furthermore, information gained from interviews shows that the prototype should be self-explanatory to be easily understood. Expert E2 stated : *"It might be important to create something here that says to the user that you can click on it to get more information. Maybe a question mark as an help option or tooltip or something".*

In the following segment, all the collected feedback and requirements are summarized.

5.3 Summary Table of Requirements

The following tables, provide a summary of all identified requirements through interviews with both groups of interviewees. It is also mentioned whether these requirements have been met in the final prototype. Due to a lack of sufficient collected data about the patient symptoms and activities, it was not possible to implement all of the neurologists' needs. For example, the smartphone was not able to collect data about FOG, the posture of the patient, and the time to take the medications, so we could not implement them. Table 5.2 summarises the neurologists' needs, whereas table 5.3 summarises the visualization experts suggestions to create an intuitive platform..

Code	Requirements	Implemented
R1	Step length	YES
R2	Gait speed	YES
R3	Number of falls	YES
R4	Freezing of gait	NO
R5	Compare with previous visit	YES
R6	Time to take medicine	NO
R7	Normative value to compare	NO
R8	Monthly visualization of factors	YES
R9	Weekly visualization of factors	YES
R10	Daily visualization of factors	NO
R11	Monthly comparison capability	YES
R12	Weekly comparison capability	YES
R13	Daily comparison capability	NO
R14	Posture of patient	NO

Table 5.2: This table summarised all the neurologists' requirements.

Code	Suggestions	Implemented
S1	Heading for each individual visualization	YES
S2	Visualization with pie chart and line graphs	YES
S3	Overview diagrams	YES
S4	Breadcrumbs	YES
S5	Correct position of charts to keep the relations	YES
S6	Correct position of filtering option	YES
S7	Adding tooltip	YES
S8	Adding help option	YES
S9	Adding search menu	YES
S10	Adding customize option	YES

Table 5.3: This table summarised all the visualization experts suggestions.

CHAPTER 6

Final Prototype

As it was described in the chapter 5, according to all interviews with neurologists and visualization experts, five iterations of the prototype were developed. Then, based on all the gather feedback, the sixth iteration as the final prototype was designed. The following chapter is in accordance with the data collection, architecture, and implementation of the final prototype. Details of the prototype components are described and the documentation highlights how the final prototype was designed based on the interviews and examinations conducted earlier.

6.1 Data for Visualization

As described in the chapter 4 , for the initial prototype design, the collected data belonged to a healthy person. To bring the data closer to real life and to address the potential design challenges, the further iterations and the final prototype were implemented using real data collected by Parkinson's patient. A patient was asked by Fraunhofer AICOS to use a smartphone during his daily life in order to gather data for the research. The information was collected for about four months from 21.08.2019 to 17.12.2019, however, to execute the prototype data needed to be collected over one year. Therefore, instead of extending the time of the research, the four months result was taken and copied in order to fabricate a year-long result.
The collected data by the patient was extracted to an excel file, to be utilized in further processes. Figure 6.1 demonstrates the art of patients' collected data in an Excel file. In the original version of the Excel file, there was no information about the patient's fall since the patient did not experience falling or the mobile phone was not with him to record the data. As this factor was one of the most integral factors for neurologists to recognise the disease progression, the data was manually created in order to allow its visualization. Although a wide range of Parkinson's patients experience falls during their daily life, however the number of falls is not too much daily. Therefore, numbers between

zero and two were considered randomly for the number of falls on different days to bring the visualization to the real state. Consequently, the data displayed in the "Number of Falls" diagram was not collected by the Parkinson's patient and is not real data.

1	Date	TypeID	Spalte1	NoUseE	NoUseM	TiltT	TiltE	TiltM	WalkT	WalkE	WalkS	WalkD	WalkM	RunT	RunE	RunS	RunD	RunM	SitT	SitM	StandT	StandM	Calories
2	21.08.2019	Daily	numFalls	1,43762E+16	-	3935	3,58165E+16	-	3430	264.70269775390625	5187	3457.49169921875	-	5	0.8761375546455383	-	10	-	1285	-	725	-	3,5006E+14
3	22.08.2019	Daily	0	8,54438E+13	-	1030	8,92112E+13	-	205	15.258275985717773	320	193.9442596435547	-	-	-	-	-	-	80	-	-	-	6,82932E+15
4	23.08.2019	Daily	0	4,24506E+15	-	8840	7,32752E+11	-	6375	466.890380859375	9175	5859.40576171875	-	5	0.8761375546455383	-	10	-	3490	-	1290	-	5,47012E+15
5	24.08.2019	Daily	1	2,25137E+16	-	3650	3,03563E+15	-	3170	235.52877807617188	4694	2989.638916015625	-	10	1.7522751092910767	-	20	-	1710	-	85	-	2,37213E+16
6	25.08.2019	Daily	0	3,52625E+15	-	2840	2,47526E+15	-	1225	92.39305877685547	1893	1186.3944091796875	-	5	0.8761375546455383	-	10	-	335	-	185	-	1,93354E+15
7	26.08.2019	Daily	0	1,32912E+16	-	5810	4,86723E+15	-	5450	412.4706420898437 5	8149	5310.22412109375	-	5	0.8761375546455383	-	10	-	1855	-	1350	-	4,26566E+16
8	27.08.2019	Daily	0	8,68E+15	-	3615	3,20675E+15	-	1680	125.357177734375	2588	1596.484375	-	-	-	-	-	-	335	-	745	-	2,67002E+15
9	28.08.2019	Daily	0	2,52262E+15	-	7655	7,53932E+14	-	4120	303.60894775390625	6112	3829.017578125	-	20	3.5045502185821533	-	40	-	2960	-	570	-	6,14714E+15
10	29.08.2019	Daily	0	2,52262E+16	-	2805	2,29031E+16	-	1310	95.85163116455078	1964	1202.0225830078125	-	10	1.7522751092910767	-	20	-	485	-	675	-	1,52834E+15
11	30.08.2019	Daily	1	1,38337E+16	-	8030	6,89903E+14	-	9760	728.0196533203125	15088	9269.263671875	-	-	-	-	-	-	1790	-	1965	-	5,88394E+15
12	31.08.2019	Daily	0	3,3635E+16	-	9240	7,74002E+15	-	5335	395.0760803222656	8004	5001.84814453125	-	15	2.6284127235412598	-	30	-	3295	-	3710	-	5,69279E+15
13	01.09.2019	Daily	0	2,40056E+16	-	14155	1,2213E+14	-	10150	726.902587890625	14899	8957.259765625	-	15	2.6284127235412598	-	30	-	4895	-	1980	-	8,78613E+15
14	02.09.2019	Daily	0	1,99369E+16	-	7010	5,78515E+15	-	5405	397.6122131347656	7992	5007.666015625	-	5	0.8761375546455383	-	10	-	2825	-	1730	-	4,24694E+15
15	03.09.2019	Daily	0	1,55969E+16	-	4790	3,81159E+15	-	2800	204.72621154785156	4057	2565.877197265625	-	5	0.8761375546455383	-	10	-	1395	-	1245	-	2,51687E+16
16	04.09.2019	Daily	0	2,41412E+15	-	7280	6,01495E+15	-	3200	234.989990234375	4720	2955.4072265625	-	30	5.2568254470825195	-	60	-	3940	-	690	-	4,0918E+16
17	05.09.2019	Daily	0	1,42406E+16	-	2775	2,1946E+16	-	3925	283.28759765625	5545	3513.347412109375	-	-	-	-	-	-	790	-	225	-	1,51181E+16
18	06.09.2019	Daily	0	2,52262E+16	-	7780	6,31374E+15	-	3000	220.5456237792968 8	4370	2776.17211914062 5	-	10	1.7522751092910767	-	20	-	2180	-	1435	-	3,98997E+16
19	07.09.2019	Daily	0	1,736E+16	-	2880	2,38901E+16	-	2095	156.49655151367188	3065	1994.7657470703125	-	5	0.8761375546455383	-	10	-	575	-	1315	-	2,04928E+16
20	08.09.2019	Daily	0	1,6275E+16	-	9000	7,42204E+14	-	4275	313.4509582519531	6346	3937.3740234375	-	10	1.7522751092910767	-	20	-	5390	-	510	-	4,9186E+15
21	09.09.2019	Daily	0	1,13925E+16	-	2560	2,00248E+15	-	440	33.80107116699219	679	440.0259094238281	-	-	-	-	-	-	3020	-	-	-	1,19762E+16
22	10.09.2019	Daily	0	1,83094E+15	-	5905	4,57774E+15	-	4410	326.1792297363281	6368	4125.6376953125	-	5	0.8761375546455383	-	10	-	4985	-	1835	-	2,84852E+15
23	11.09.2019	Daily	0	2,37344E+16	-	3790	2,81923E+15	-	2985	227.63394165039062	4578	2947.3251953125	-	5	0.8761375546455383	-	10	-	615	-	85	-	1,88189E+15
24	12.09.2019	Daily	0	3,96025E+16	-	3870	3,0543E+16	-	2450	182.46649169921875	3598	2320.388671875	-	10	1.7522751092910767	-	20	-	955	-	935	-	2,26786E+16
25	13.09.2019	Daily	1	1,20435E+16	-	4255	3,26836E+15	-	2820	204.427001953125	4132	2544.410888671875	-	15	2.6284127235412598	-	30	-	795	-	625	-	1,74646E+16
26	14.09.2019	Daily	0	5,03168E+15	-	7495	6,31116E+15	-	6020	441.5617980957031	8929	5548.2685546875	-	10	1.7522751092910767	-	20	-	2665	-	2125	-	4,65177E+16
27	15.09.2019	Daily	0	1,04431E+16	-	7760	6,90203E+15	-	3935	291.4786376953125	5963	3691.027099609375	-	15	2.6284127235412598	-	30	-	2495	-	320	-	5,36775E+15
28	16.09.2019	Daily	0	9,62938E+15	-	1280	1,18713E+16	-	75	5.512293338775635	115	69.37388610839844	-	-	-	-	-	-	25	-	-	-	9,26632E+15
29	17.09.2019	Daily	1	2,03437E+16	-	6180	5,08047E+15	-	4705	355.37017822265625	7041	4568.1411328125	-	10	1.7522751092910767	-	20	-	1935	-	1220	-	4,0433E+15
30	18.09.2019	Daily	0	2,56331E+16	-	2980	2,32964E+15	-	3125	250.96249389648438	5332	3371.368896484375	-	5	0.8761375546455383	-	10	-	465	-	270	-	2,53066E+14
31	19.09.2019	Daily	0	2,4955E+15	-	7650	6,24425E+15	-	8555	623.5488891601562	12851	7795.33251953125	-	20	3.5045502185821533	-	40	-	3305	-	630	-	4,50398E+15
32	20.09.2019	Daily	0	3,71613E+15	-	3180	2,46809E+16	-	2205	159.06808471679688	3219	1971.9732666015625	-	-	-	-	-	-	1095	-	730	-	1,4128E+16
33	21.09.2019	Daily	0	1,77669E+16	-	2185	1,60341E+15	-	3725	272.2664489746094	5348	3411.44140625	-	5	0.8761375546455383	-	10	-	840	-	120	-	1,25242E+15
34	22.09.2019	Daily	0	1,6275E+16	-	2760	2,52176E+16	-	485	37.51240921020508	726	490.775634765625	-	-	-	-	-	-	630	-	20	-	2,05682E+16
35	23.09.2019	Daily	0	1,57325E+16	-	1840	1,6645E+16	-	540	42.33937072753906	822	559.3739624023438	-	-	-	-	-	-	355	-	220	-	1,38993E+16
36	24.09.2019	Daily	0	1,76313E+16	-	640	5,03311E+16	-	370	28.254602432250977	548	366.2037353515625	-	5	0.8761375546455383	-	10	-	70	-	-	-	3,7629E+15
37	25.09.2019	Daily	0	1,085E+16	-	3010	2,56443E+16	-	3970	293.17529296875	5973	3703.6181640625	-	-	-	-	-	-	2095	-	380	-	2,15E+15
38	26.09.2019	Daily	0	2,03437E+16	-	4575	3,75061E+15	-	4800	366.24188232421875	7104	4743.87548828125	-	25	4.380687713623047	-	50	-	1375	-	2150	-	3,48609E+16
39	27.09.2019	Daily	0	2,69894E+16	-	7245	5,54251E+15	-	4395	324.4215087890625	6450	4096.9609375	-	90	15.770478248596191	-	180	-	4750	-	1395	-	3,59212E+15
40	28.09.2019	Daily	0	3,906E+15	-	9845	7,97867E+15	-	6615	499.2504577636719	9961	6413.93798828125	-	70	12.2659273147583	-	140	-	2415	-	1740	-	5,92751E+15

Figure 6.1: Collected data by a Parkinson's patient via smartphone exported in Excel

6.2 Architectural Overview and Used Technologies

As an iterative design process was conducted, we had to rework on the prototype after each Interview. To speed up the development and debug the codes, we have used the Model-viewer-controller (MVC) pattern for this work. The architecture of this project consists of 3 different layers such as Business, Model, and User interface layers.
In the following segment, detail about each layout is outlined:

Business layer: In this layout, the main operations of the program were performed. At first, the collected data that is exported in an Excel file should be read and imported to the program. For this aim, an interface is designed that if we needed to change the components during the project, the dependence between the other layers and the component layers that operate reading the Excel file would be reduced to easily make the required changes in the project. Initially the Microsoft Excel library was used, however due to the amount of available data, the speed of reading information from the Excel file was extremely slow. So, we decided to use the EPPlus [1] library to read the Excel file, which greatly increased the speed of importing the Excel file into our platform (See Figure 6.2).

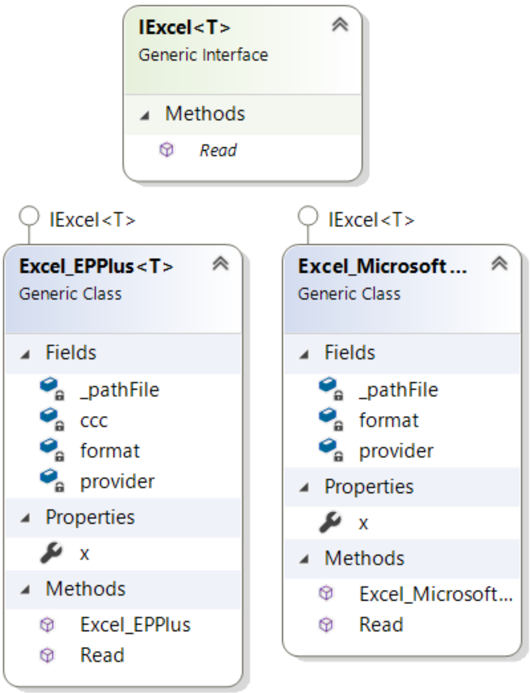

Figure 6.2: Interface and Excel implementation classes

[1] https://www.epplussoftware.com/

In the classes shown in the Figure 6.3, the amount of activity of the patient is extracted according to the year, month and day.

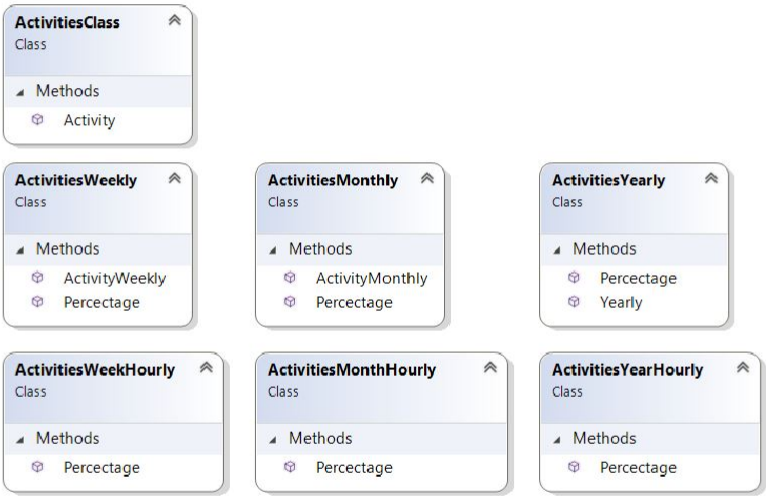

Figure 6.3: Interface and activities implementation classes

In the classes shown in the Figure 6.4, the amount of average activity of the patient is extracted according to the year, month and day.

In the classes shown in the Figure 6.5, the amount of number of falls of the patient is extracted according to the year, month and day.

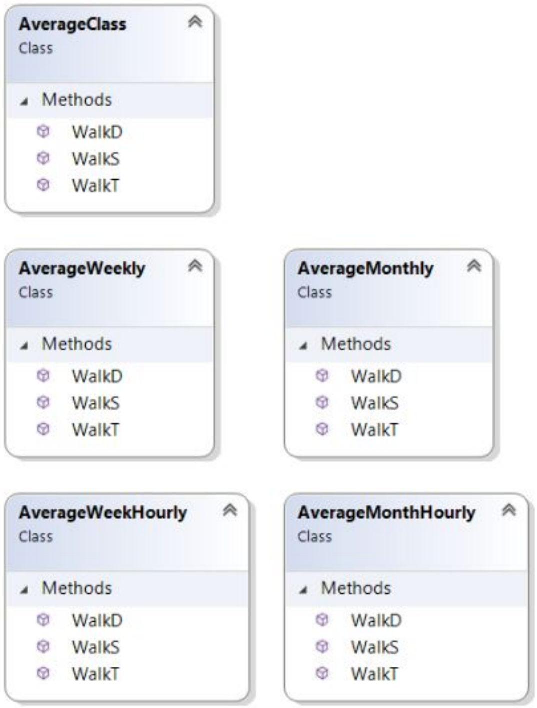

Figure 6.4: Interface and average activities implementation classes

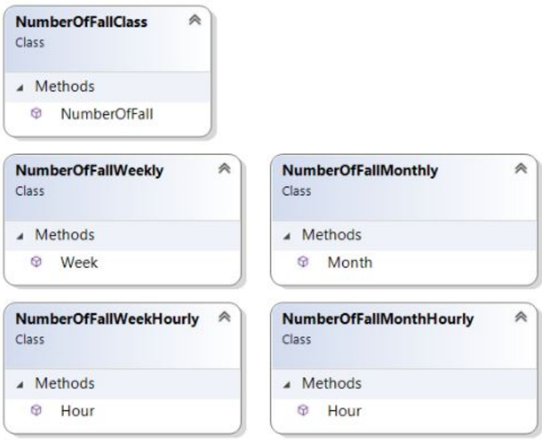

Figure 6.5: Interface and number of falls implementation classes

Model layer: For working with intended data, according to Excel file various models are implemented and placed in this layout.

User Interface layer: In this layer, according to the request of the user the desired processing is performed and the result is returned to the user.

In terms of back-end technologies, we used C# for importing the Excel file and processing the data. Besides, we used C# libraries such as .NET Framework [2] and EPPlus to speed up developing the program.
.NET is a framework that is created by Microsoft and provides a way to develop an application faster and EPPlus is a .NET library that read and writes Excel files.

In terms of front-end technologies, based on our previous knowledge, different programming languages such as HTML, CSS, and JavaScript were used. Moreover, multiple libraries such as Bootstrap [3], jQuery [4], and Ploty.js were used in order to facilitate the development of our prototype.

- Bootstrap: Bootstrap is a free and open-source library which contains HTML and CSS design template and using it provides a way to design a website faster.
- jQuery: jQuery is one of the free and open source JavaScript libraries which is most populaR [62].
- Ploty JavaScript Graphing Library: Plotly.js is a library ideally suited for JavaScript applications which make use of graphs and charts [63].

6.3 Implementation and Details of Final Design

The basic structure of the final prototype consists of three different main screens.

1. A list of all patients and search menu (Default page) (See Figure 6.6)
2. Overview of patients symptoms and activities (Overview page) (See Figure 6.7)
3. Details about patients symptoms and activities (Details page) (See Figure 6.8)

A list of all patients and search menu:
This view is presented to the user as the default view. It contains a list of all patients, with their names, ages, and genders, who have already been visited by the neurologists. At the top of the page, the "Search" button for finding patients and "All patients" button for visiting the list of patients were implemented. To speed up finding a specific patient or visiting the list of all patients at any time, this menu bar is shown not only on the default page, but also on the overview page. The user starts to work with the platform by searching for a patient's name and then the overview page will appear. To reduce the

[2]https://docs.microsoft.com/en-us/
[3]https://getbootstrap.com/
[4]https://jquery.com/

searching time an auto-complete feature is implemented, which can predict the rest of the patients' name.

Overview of patients symptoms and activities:
This page provides a comprehensive view of the patient profile, time frame, and all monitored factors. Subsequently, we will describe these factors in more detail.

Details about patients symptoms and activities:
If users need to get more details regarding the information displayed on the overview page, they could access the details screen by clicking on each point corresponding to the desired month or week. On this page, the users can customise the information according to their needs.
In the following section, the most important components and features of the prototype are outlined. Clarification will be made as to how the came to this user interface based on various interviews.

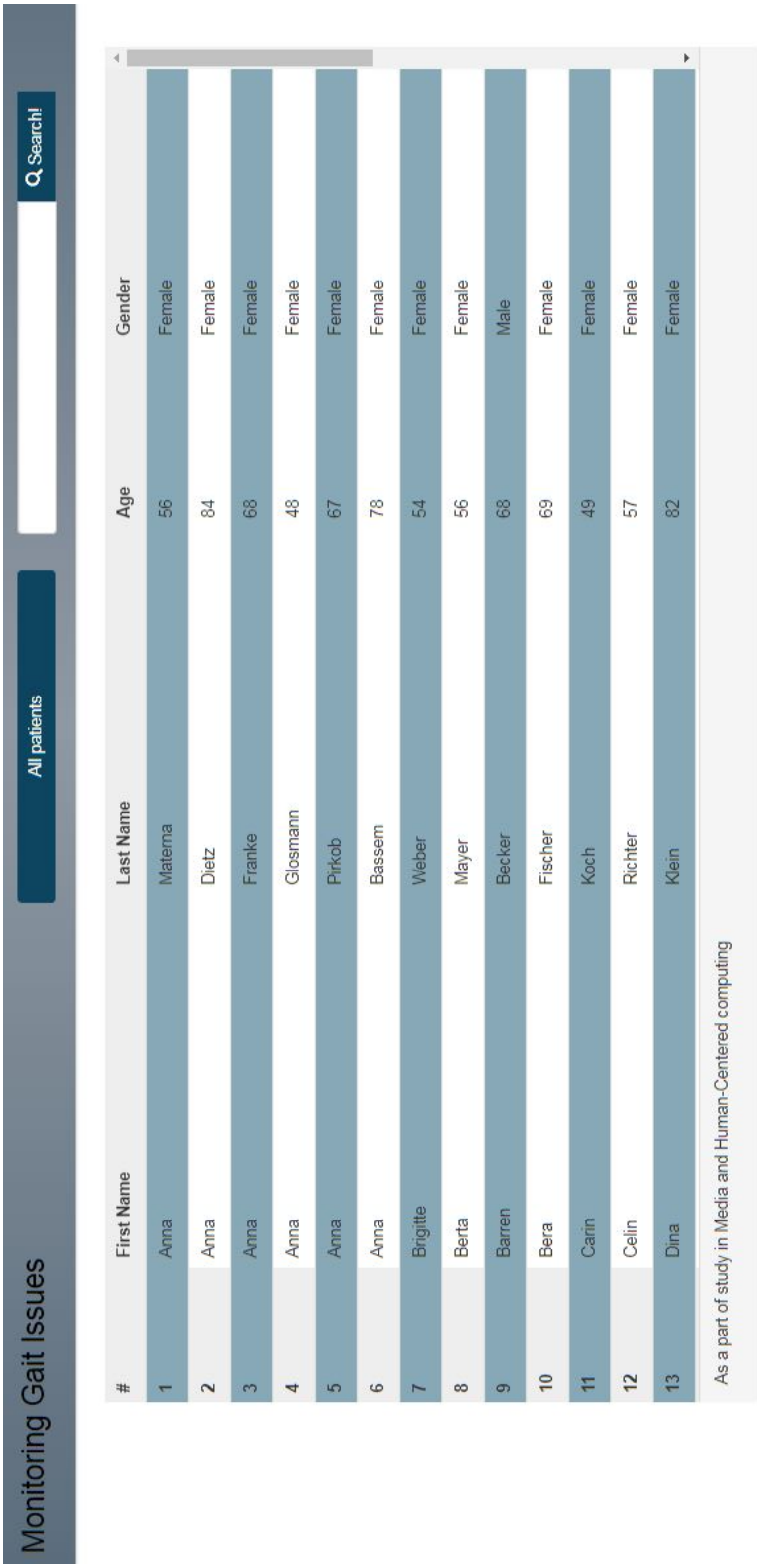

Figure 6.6: list of all patients and search menu to find new patient

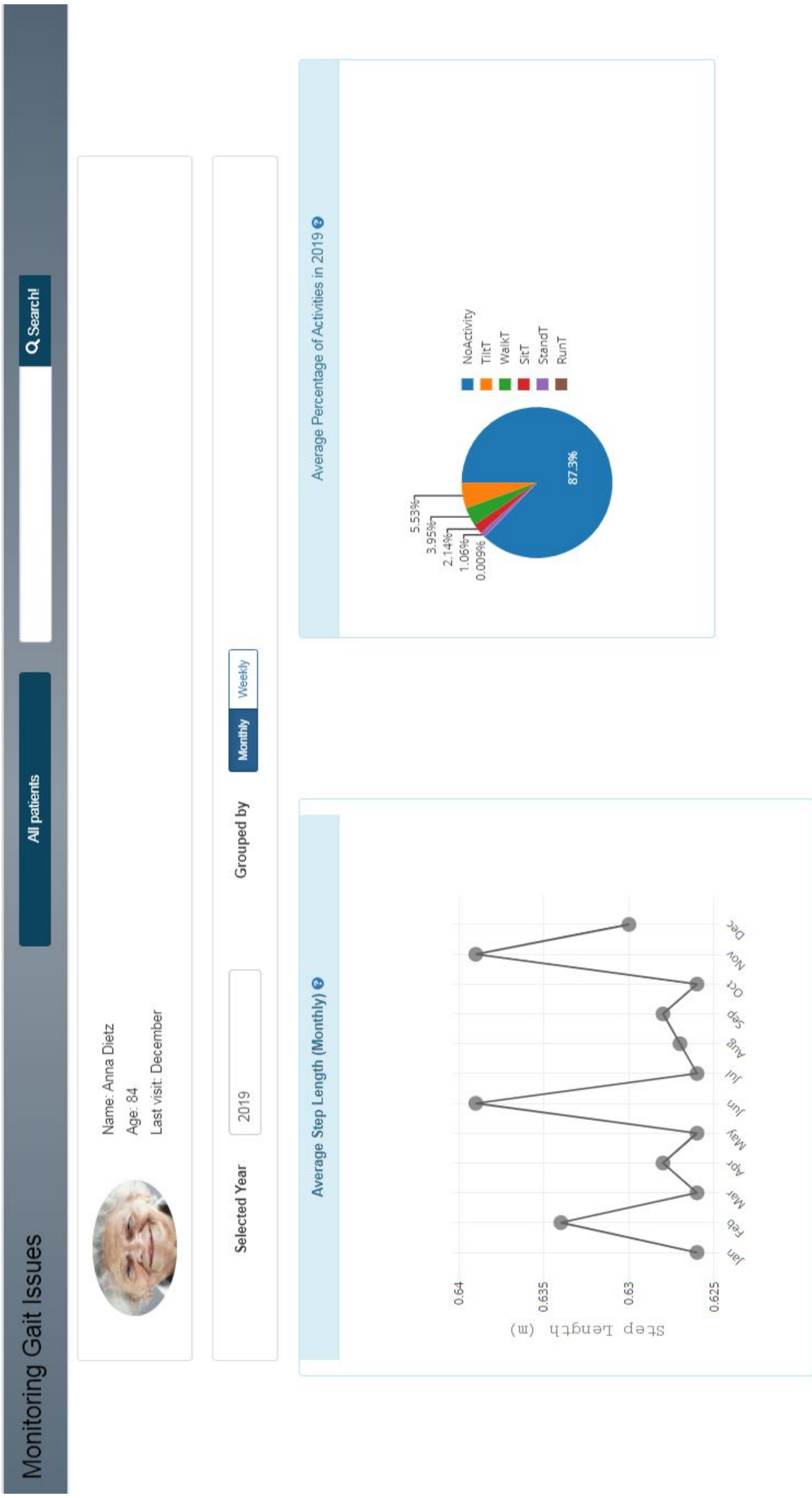

Figure 6.7: Part of the overview of patients symptoms screen

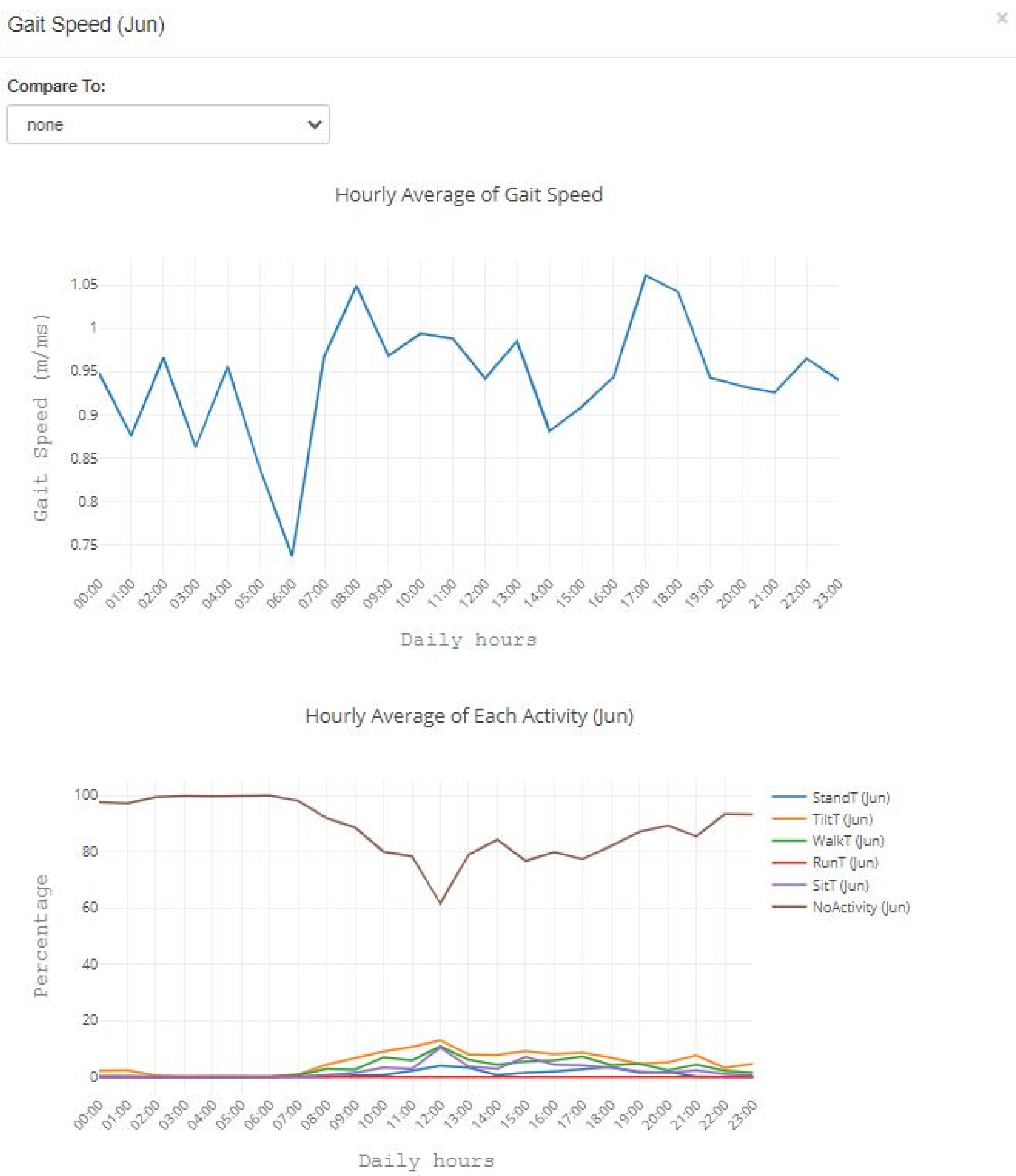

Figure 6.8: Details screen about patients symptoms

6.3.1 Possibility to Select Different Time Frame

One of the most important aspects that needed to be verified in the prototype was the visualization of the collected data in various time frames to understand the disease progression and ramifications of alternative medication more accurately.

Based on all collected feedback, we realized that neurologists need to be informed about monitored symptoms monthly and weekly. Therefore, on the overview page, we have implemented this option and neurologists can select it if they wish to see the data displayed on the overview page monthly or weekly.
As Figure 6.9 and 6.10 illustrate, this part of visualization addresses neurologists' needs for selecting their intended time-frame.

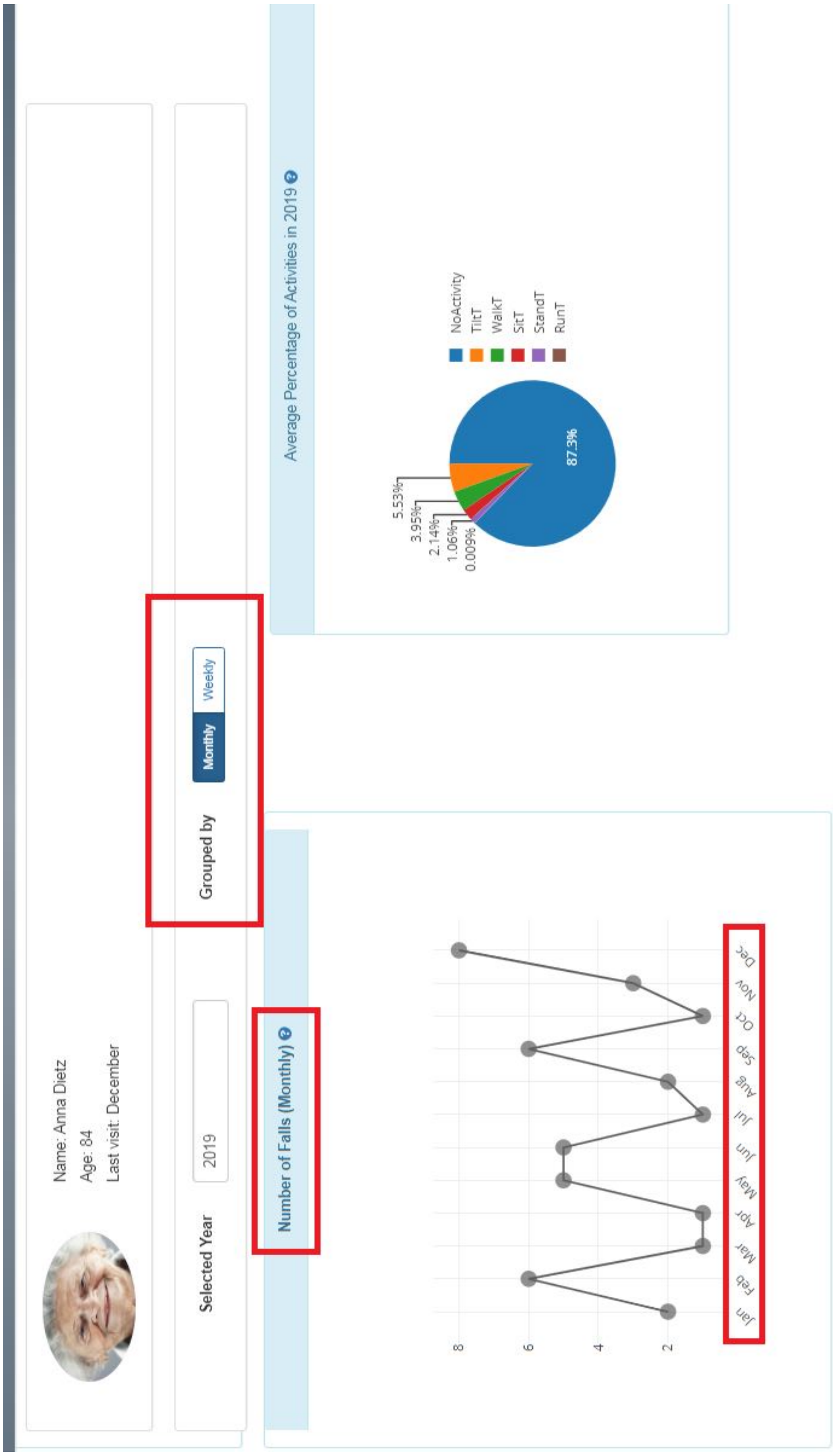

Figure 6.9: Monthly Overview of Symptoms

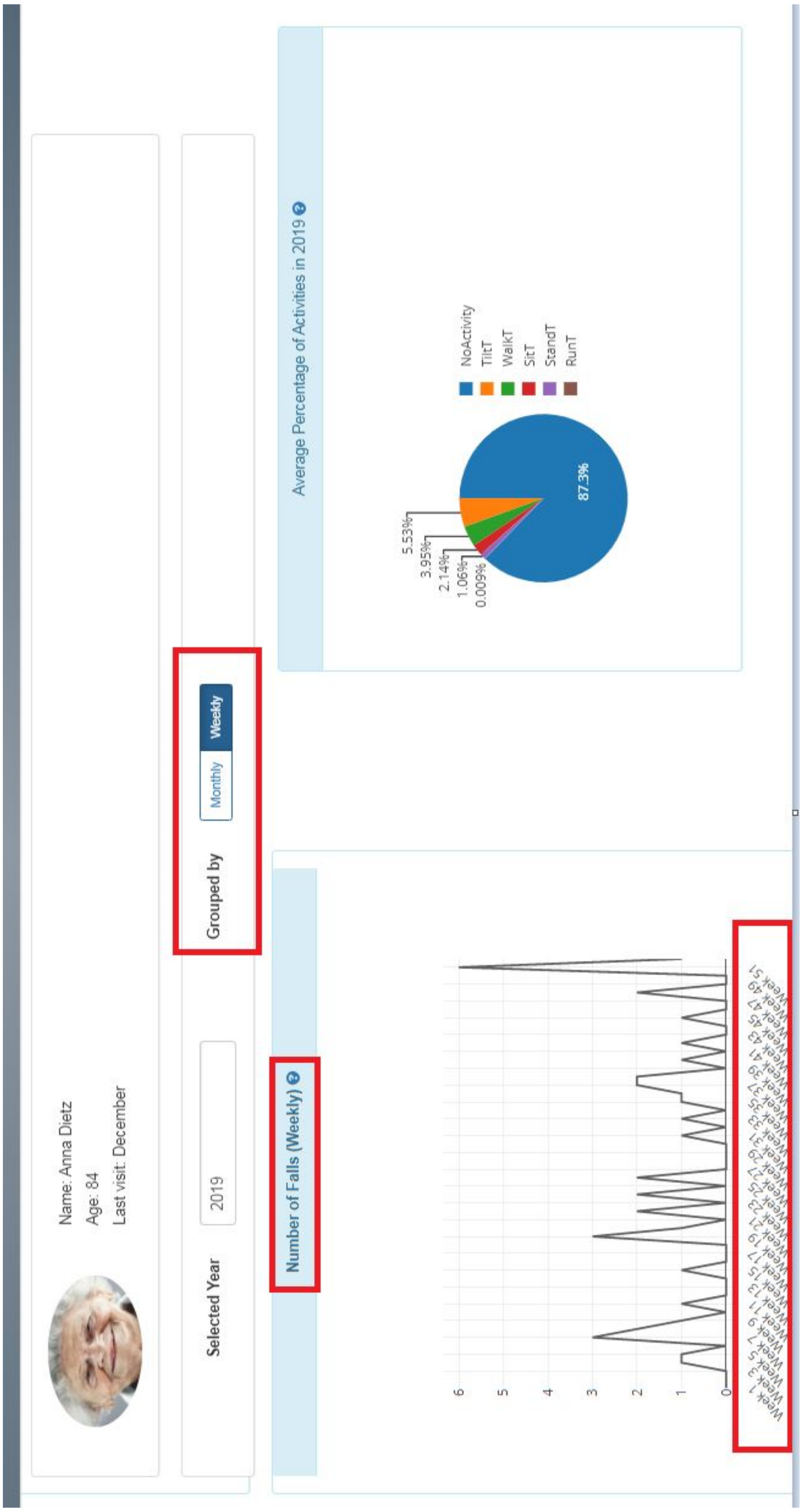

Figure 6.10: Weekly overview of Symptoms

6.3.2 Visualization of Required Factors

Average Step Length

On the overview screen, all factors required by neurologists to assess the progression of PD are demonstrated. The first diagram is according to the average step length, which could be shown monthly or weekly. Step length is defined as the covered distance divided by the number of steps. Average of step length was calculated using the following Formula:

$$Step\ length = \frac{Distance\ covered\ (WalkD)}{Number\ of\ steps\ (WalkS)}$$

$$Average\ of\ step\ length = \frac{Distance\ covered\ (WalkD)\ during\ the\ same\ month\ or\ week}{Sum\ up\ the\ number\ of\ steps\ (WalkS)\ during\ a\ month\ or\ week}$$

Figure 6.11 shows the average of step length monthly, while Figure 6.12 shows it weekly and in both diagrams, the Y-Axis shows the step length in meters while the X-Axis shows the different time frame. By hovering the mouse over each point, the step length associated with this month will appear (See Figure 6.13). To better perceive each diagram, there is a help option, displayed with a question mark, next to each header . The help option provides information not only about the type of diagram, but also about how to interact with the diagram (See Figure 6.14).

Average Gait Speed

The second diagram located on the overview page is according to the average gait speed of the patient which can be displayed monthly or weekly (See Figure 6.15). The X-Axis illustrates the time frame while the Y-Axis displays the gait speed in meters per millisecond (m/ms). Average gait speed is calculated based on the following formula:

$$Gait\ Speed = \frac{Total\ distance\ (WalkD)}{Total\ time\ (WalkT)}$$

$$Average\ Gait\ Speed = \frac{Sum\ up\ the\ total\ distance\ (WalkS)\ during\ a\ month\ or\ week}{Sum\ up\ the\ time\ (WalkT)\ during\ the\ same\ month\ or\ week}$$

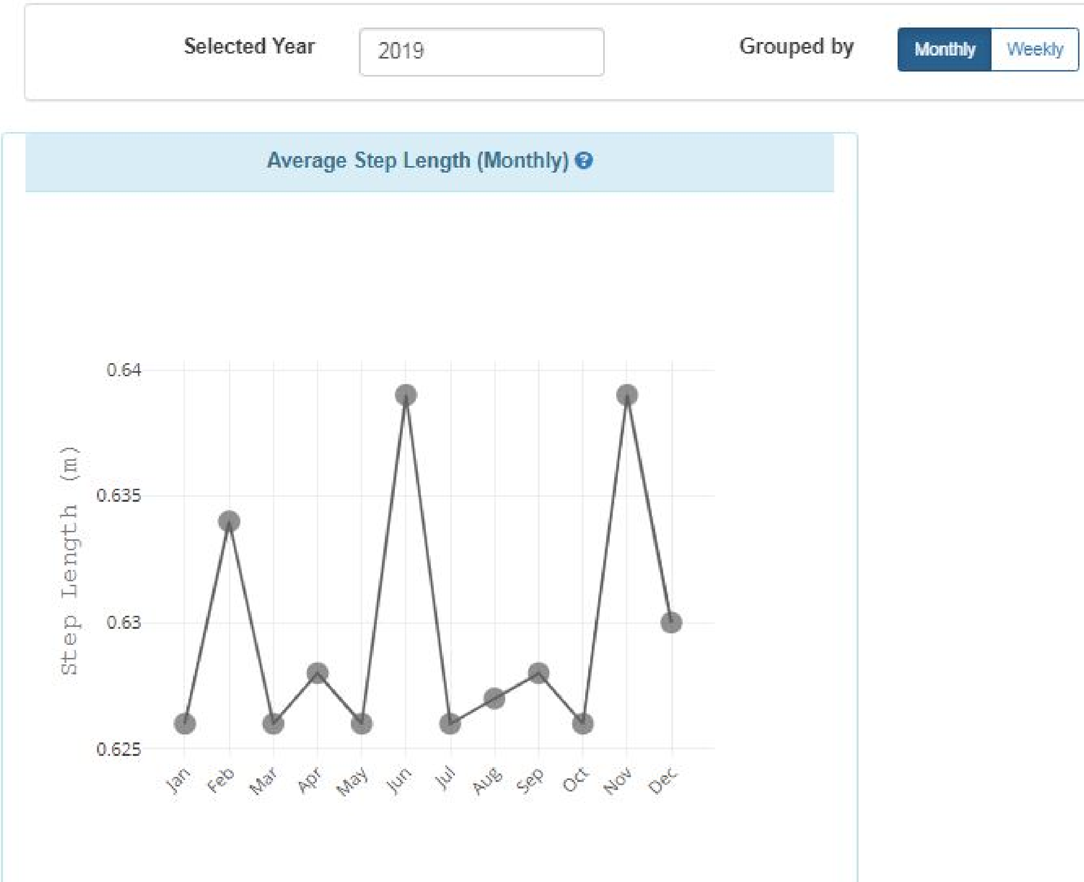

Figure 6.11: Monthly overview of average step length

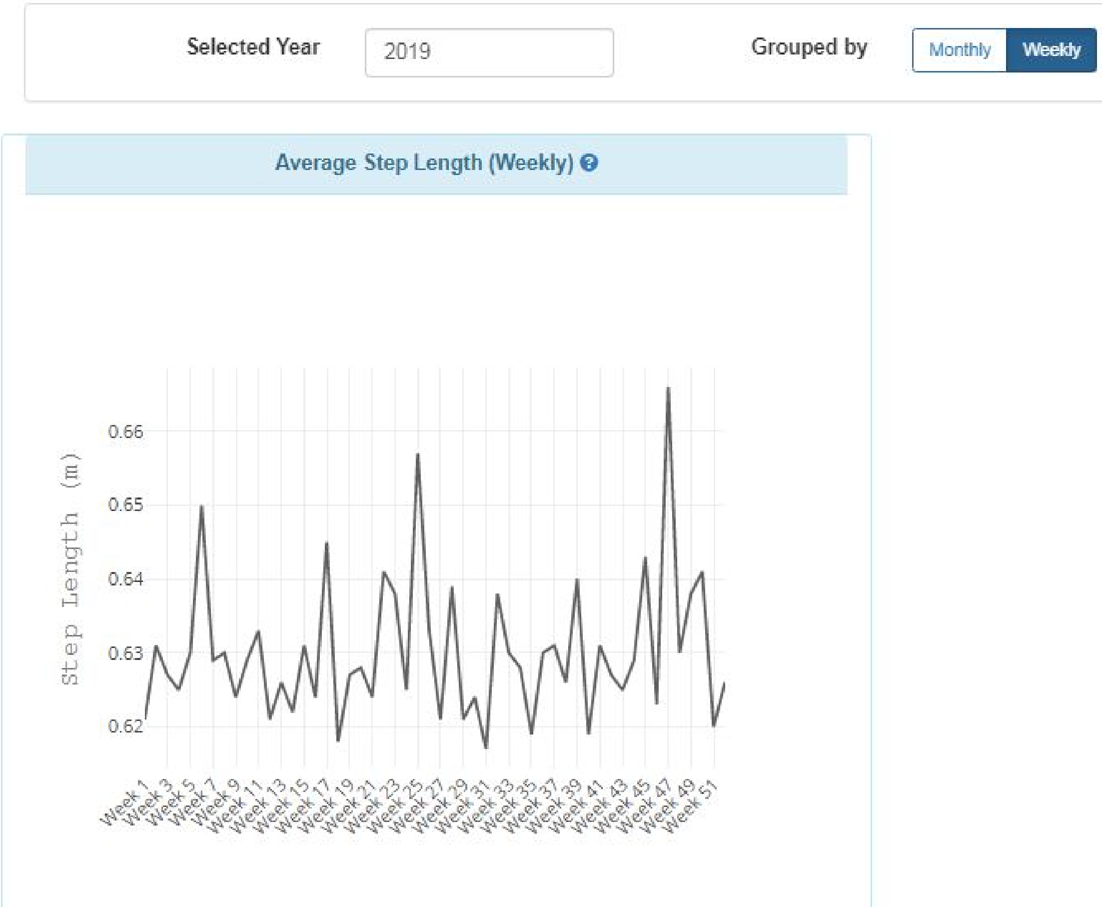

Figure 6.12: Weekly overview of average step length

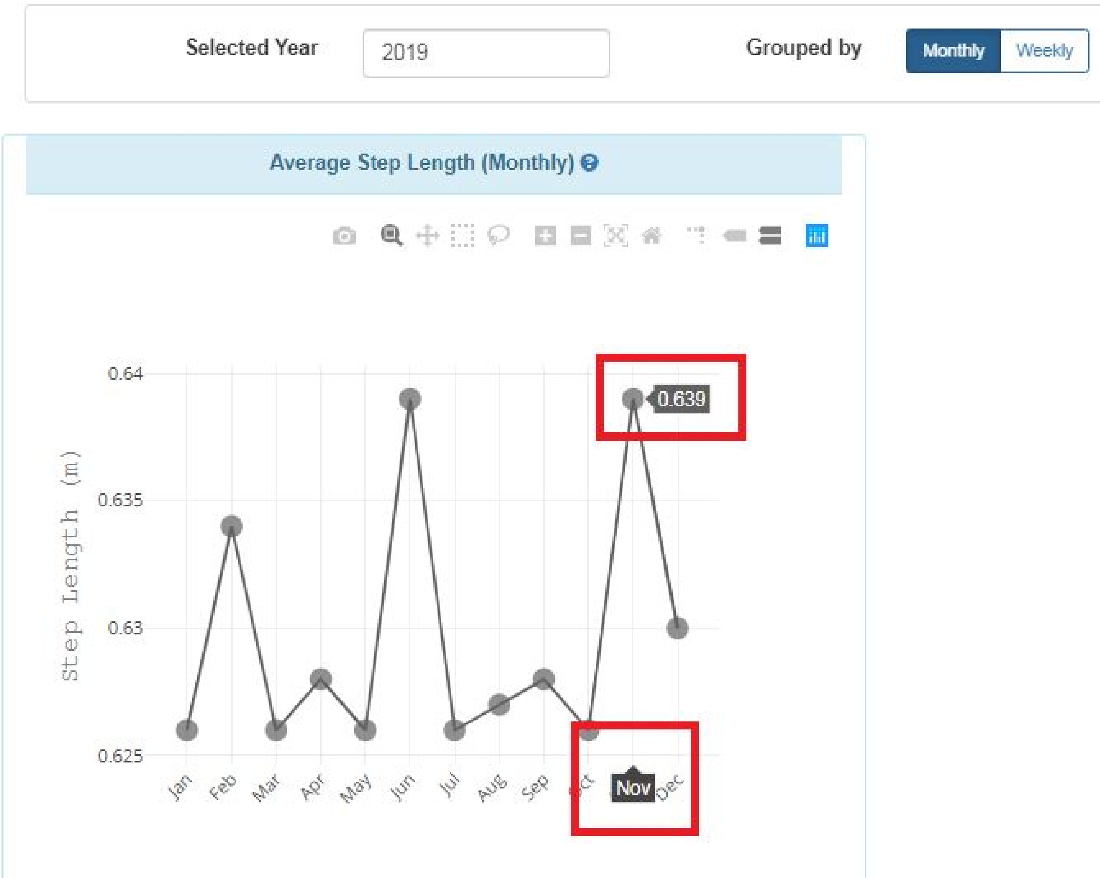

Figure 6.13: Step length associated with November accurately

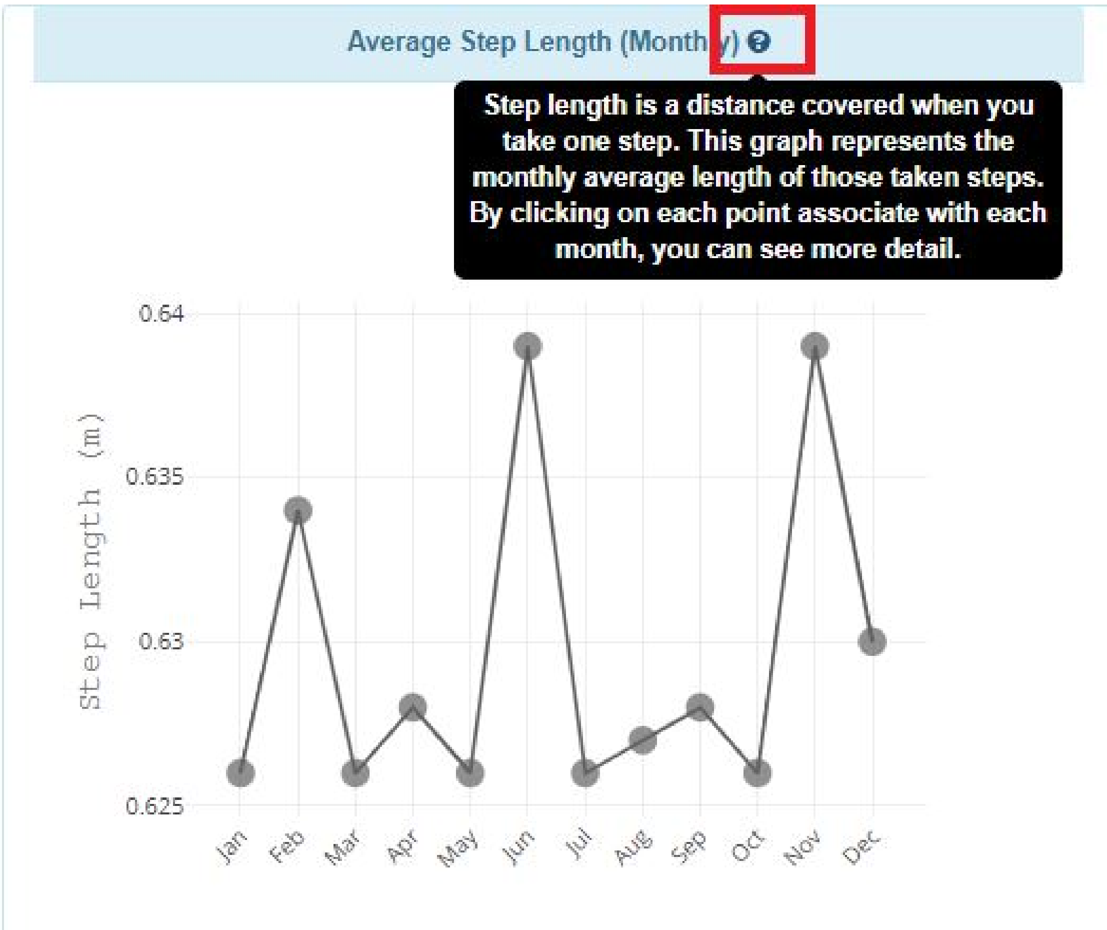

Figure 6.14: Help information which is displayed on the help icon

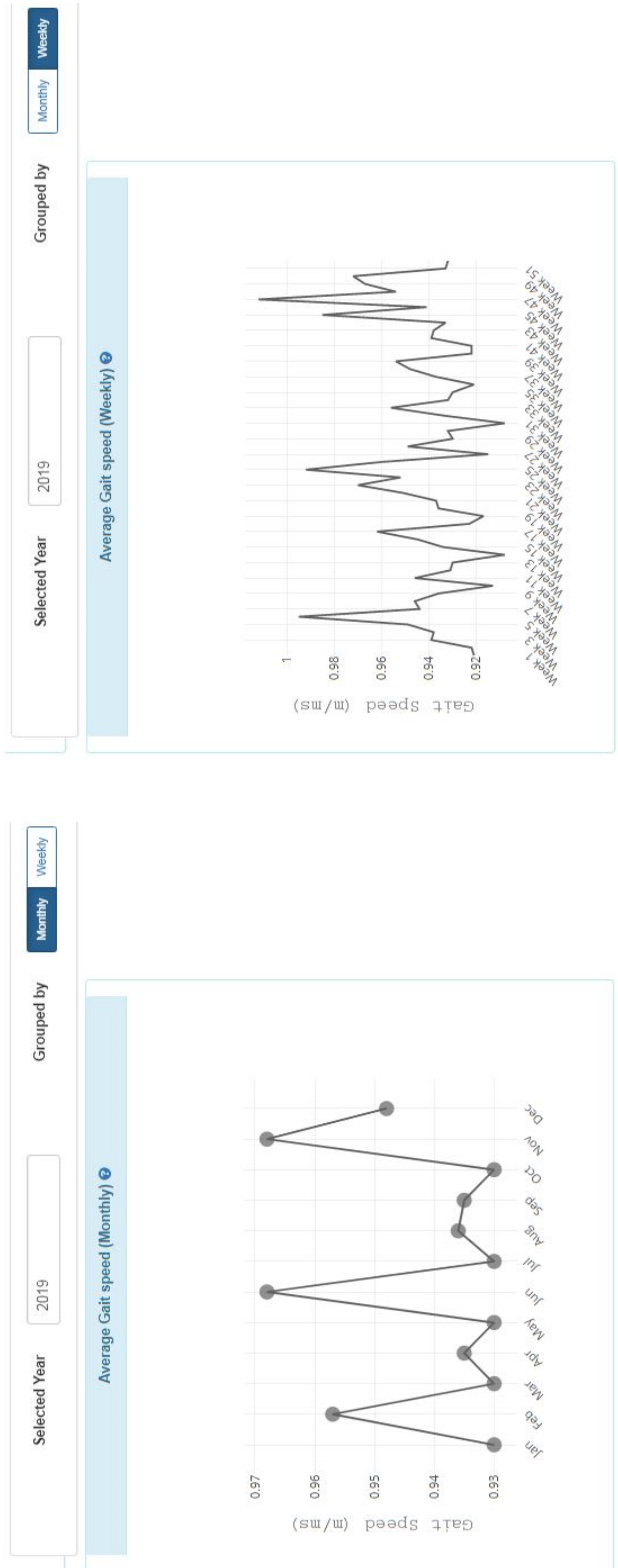

Figure 6.15: Left: Monthly overview of average gait speed. Right: Weekly overview of average gait speed

Number Of Falls

The result of the analysis of each iteration was an important basis for the next stages of prototype development. As all neurologists agreed that, number of falls could be highly important to evaluate PD, we visualized this factor to fulfill neurologists' requirements. Figure 6.16 shows the visualization according to the number of falls. To design the platform as simply as possible, all diagrams demonstrated on the overview page follow the same pattern; therefore, this diagram can also be demonstrated monthly or weekly. The X-Axis displays the time frame and the Y-Axis represents the number of falls. By comparing the number of falls during different months or even different weeks, the neurologists can be informed about disease progression with more insight.

Average percentage of activities

On the overview page, the pie chart shows the average percentage of different activities.This pie chart proved beneficial as it provided an overview of the patient's activity. This diagram presents data in three different time frames. When this page loads for the first time and the user has not yet interacted with the page, the pie chart shows the average percentage of different activities annually (See Figure 6.17). Besides, the pie chart, like other charts, can display information in both monthly and weekly intervals. If the monthly overview is selected by the user, the user can also see the average percentage of each activity related to each month on the pie chart. It is achieved by moving the mouse on data display points (See Figure 6.18) . Besides, if the weekly overview is selected by the user, the pie chart will illustrate the average percentage of each activity weekly, which has a similar pattern as the monthly overview. The user should simply move the mouse back and forth on the displayed point designated to each month in order to visit the intended data on the pie chart (See Figure 6.19).

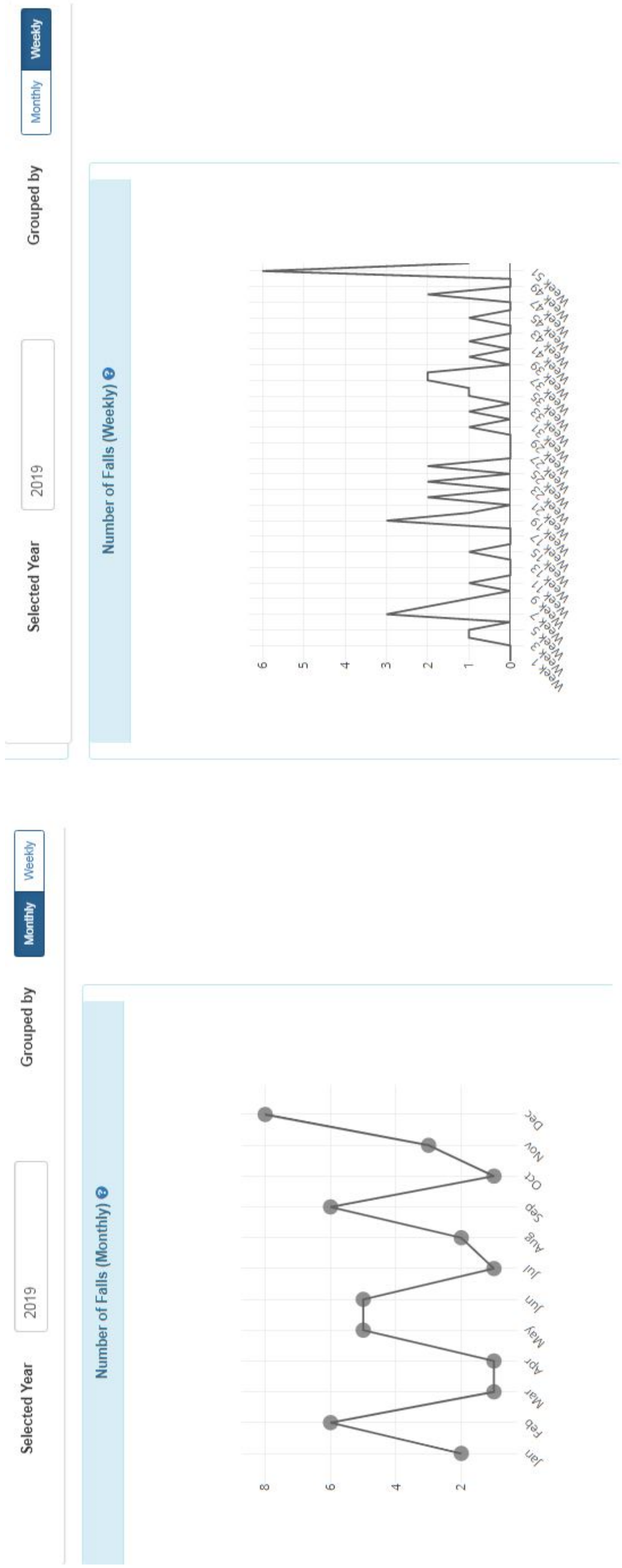

Figure 6.16: Left: Monthly overview of number of falls. Right: Weekly overview of number of falls

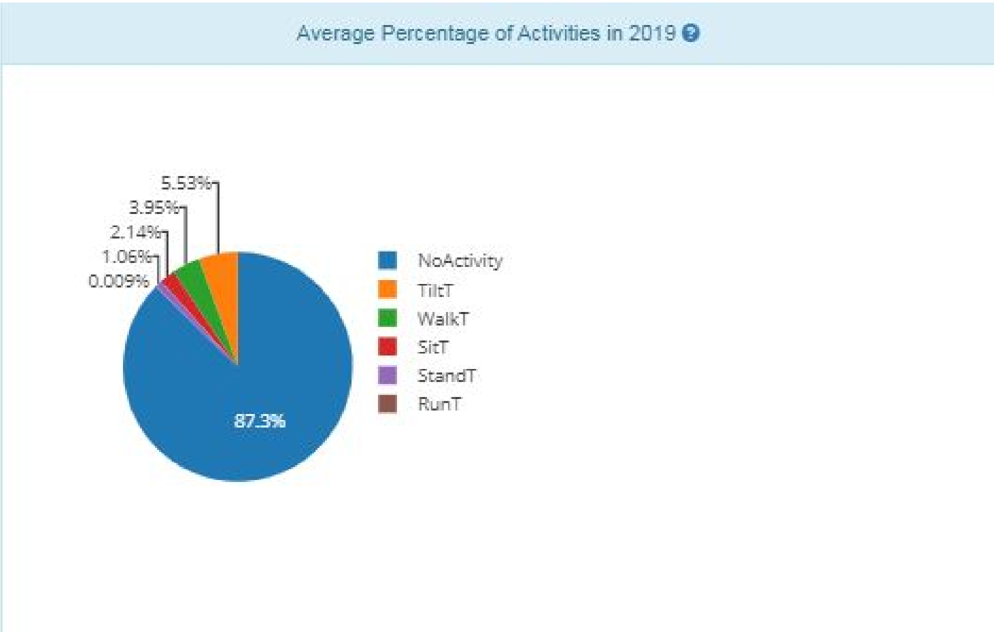

Figure 6.17: Average percentage of activities in 2019

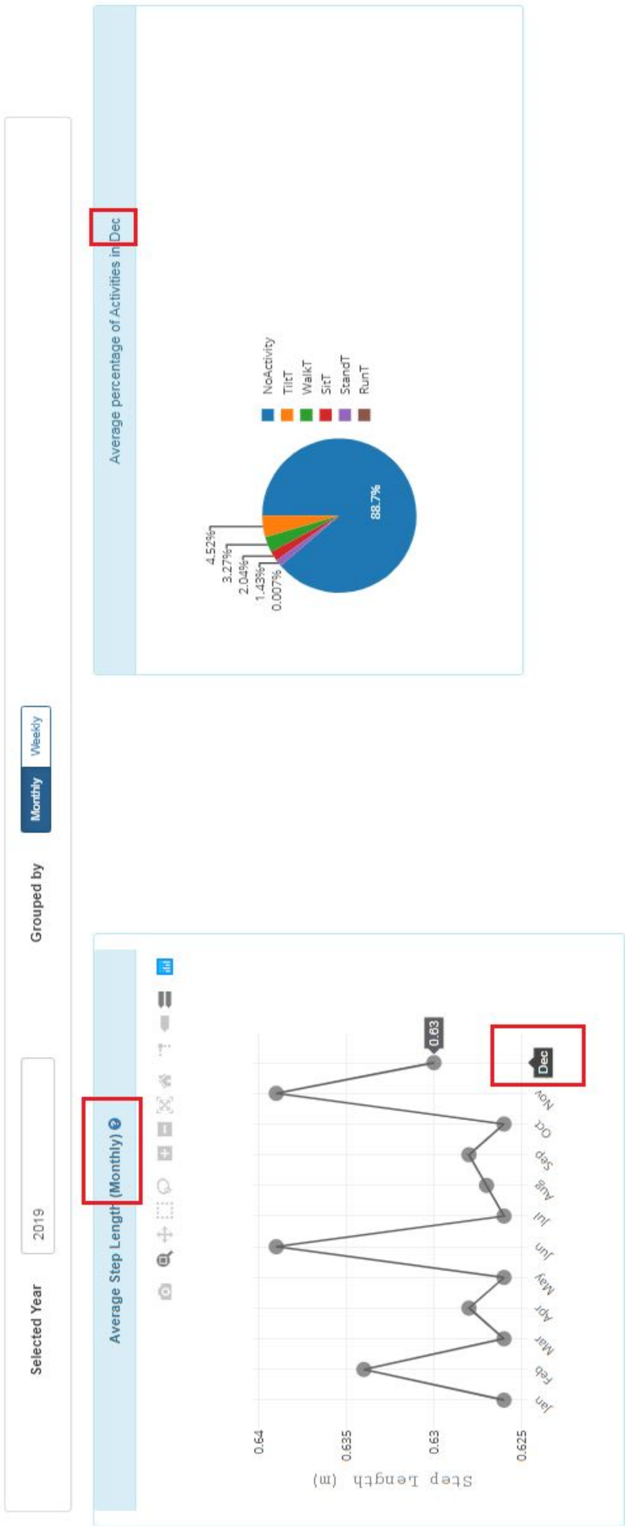

Figure 6.18: *Average percentage of activities in December*

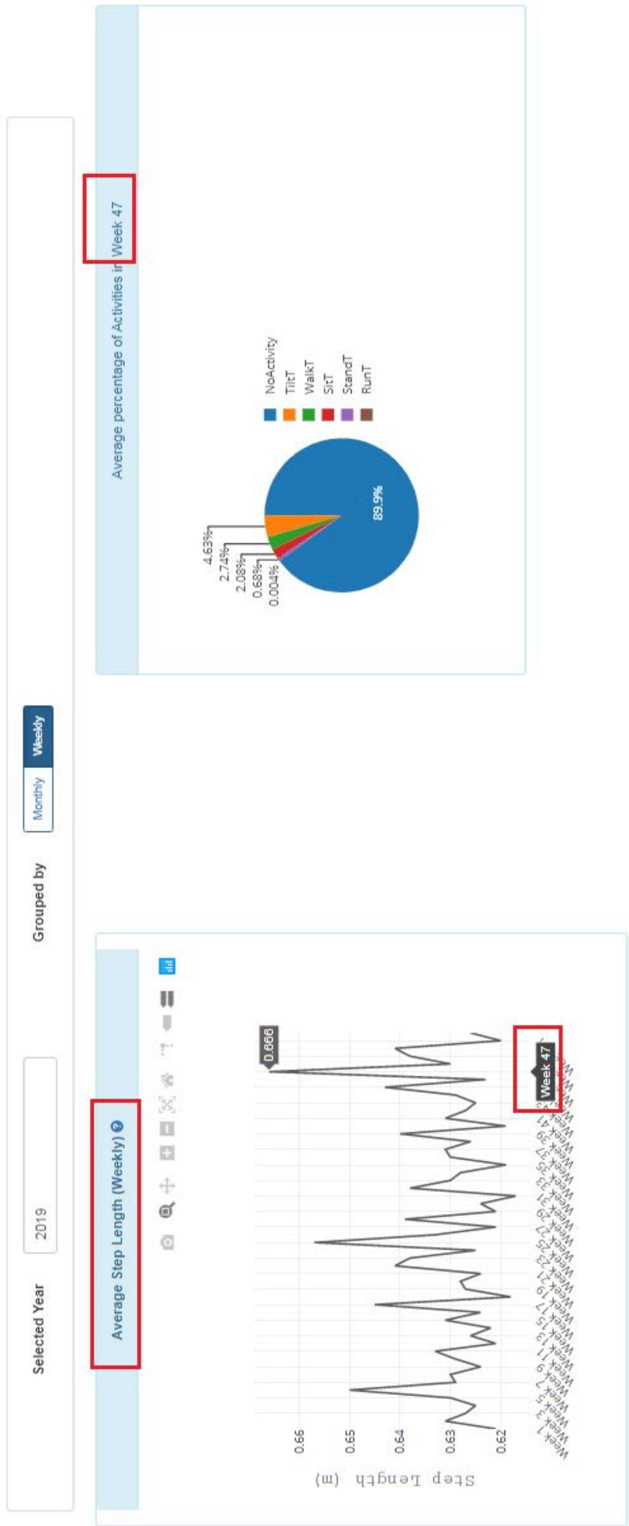

Figure 6.19: Average percentage of activities in week 47

6.3.3 Specific Data visualization

As mentioned above, the overview page of the web platform mainly focuses on the general outline of the gathered data. It means neurologists can compare ups and downs of each factor during different months or even different weeks and variations could indicate that medication does not work well. In order to identify the underlying cause, they can click on each point associated with each month, to see more details about it. The details page is displayed according to the time selected on the overview page. It means, if the user has selected the monthly display on the overview page, he can select one of the displayed points associated with one month to see the details of that month on the details page (See Figure 6.8). In addition, if the weekly information is demonstrated on the overview page, by selecting a week, the user can see more details related to this week.

Hourly Average of Each Activity

An overview of the average percentages pertaining to a patient's various activities are displayed on the overview page by the pie chart visualization which could help neurologists attain information about the percentage of patient's activities in general. However, on the details page, a chart is visualized which shows details according to the percentage of the hourly average of each activity of the patient. By using this chart, neurologists can be informed about a patient's activity-levels hourly and it could be helpful to identify the Off phases.
Like all other diagrams, this diagram can also illustrate the data according to one month or week. When the user selects a month on the overview page, this chart will show the hourly average of each activity in the selected month (See Figure 6.20) while if the user select a week, this chart will demonstrate data according to the selected time-frame (See Figure 6.21).

6.3.4 Comparison of Data and Customization

Neurologists already mentioned, the comparison of the required factors is highly important to evaluate the disease progression. Thus, this feature is implemented to address their needs. Therefore, we provided a way for them to compare the selected month or week with their intended previous times. At the top of the details page, there is a "Compare To" option. The user can compare the selected month with the last 3, 6 or 12 months (See Figure 6.22) and if the details page is illustrating a week, it is possible to compare a specific week with the last 1, 2, or 3 weeks (See Figure 6.23). The users can even customize the information that they need. As Figure 6.24 shows, the information about the displayed month can be compared not only with the previous months from the list provided in the "Compare to" section, but also with any other month based on the user's needs.

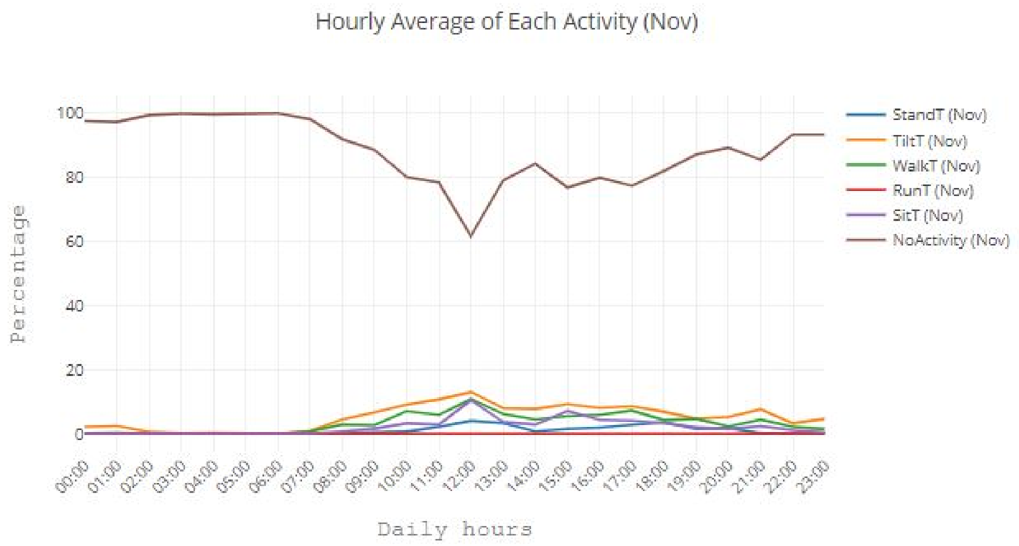

Figure 6.20: Charts according to the hourly average of each activity in November

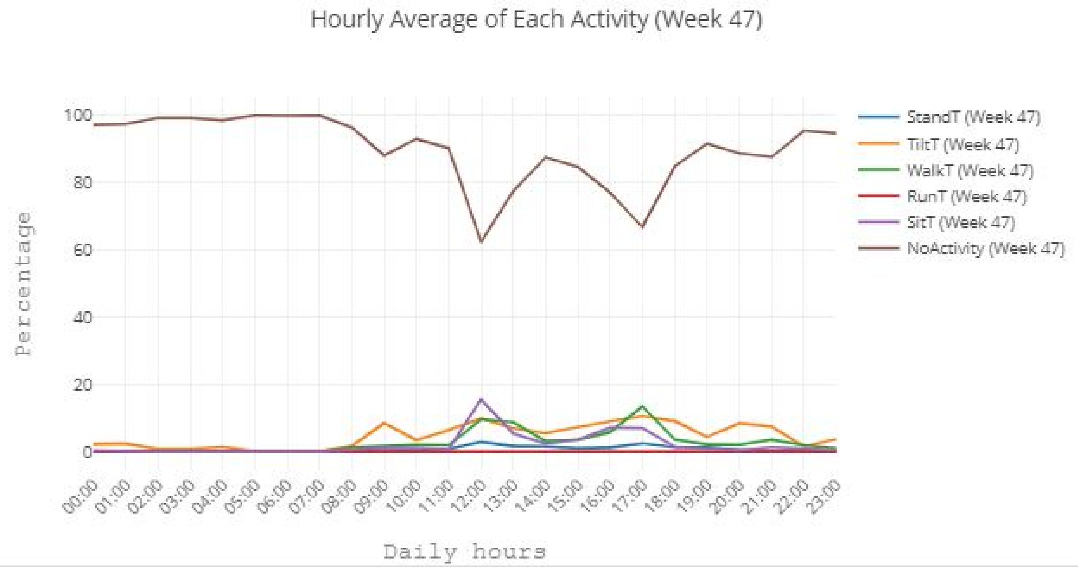

Figure 6.21: Charts according to the hourly average of each activity in Week47

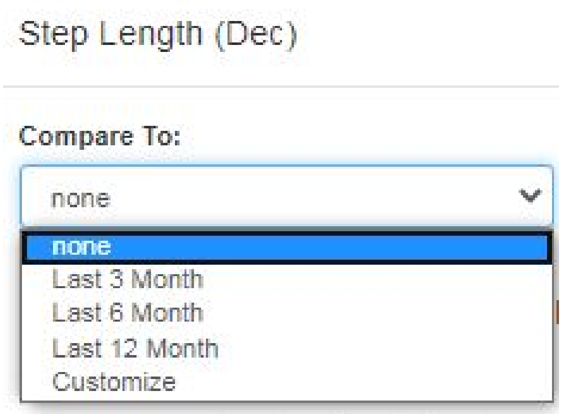

Figure 6.22: The Comparison option to compare one month with one of the suggested opportunity presented in the list

Figure 6.23: The Comparison option to compare one week with one of the suggested opportunity presented in the list

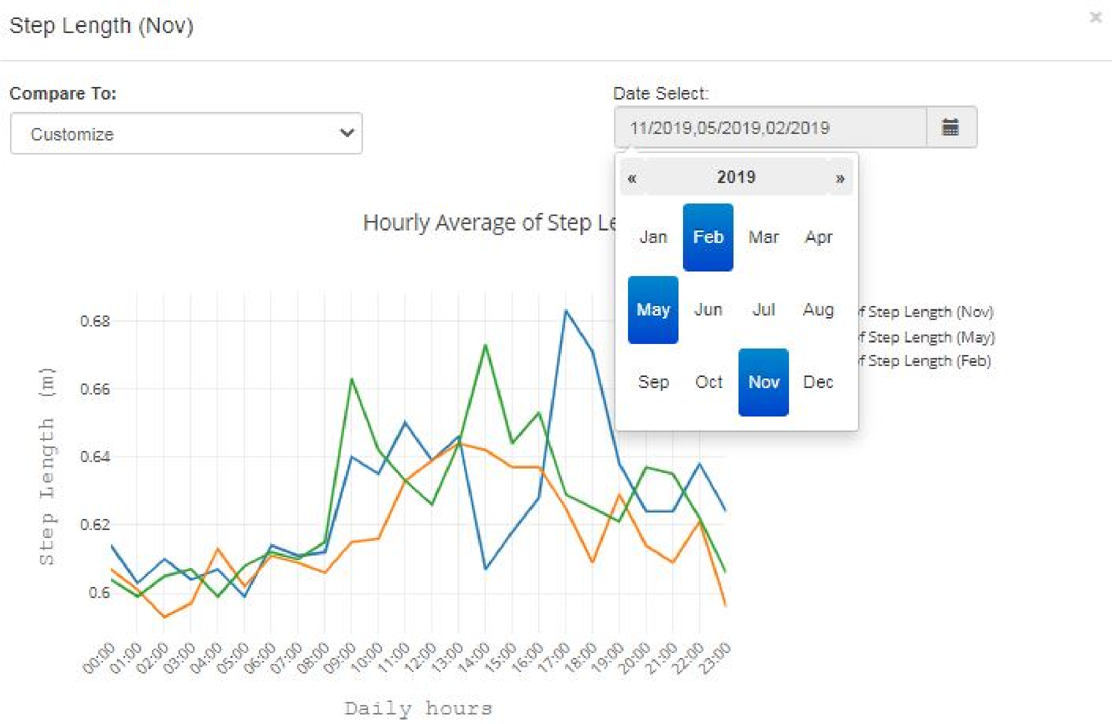

Figure 6.24: Customize option that indicates that three different months have been selected by the user

6.4 Design Evaluation

The sixth iteration was considered as the final prototype and was evaluated in order to understand if it meets the neurologists' needs and to identify possible weaknesses and strengths of the prototype. The result was analysed and possible enhancements were implemented in the "future work" section.

6.4.1 Methodology

The evaluation of the final prototype was conducted by neurologists who were the ultimate users of the system in order to get legitimate feedback. Therefore, we contacted the aforementioned neurologists who initially participated in our research as interviewees and asked them whether they were able to participate in our research again to evaluate our final prototype. Among seven participants, only neurologists N2, N3, N5, N6 were capable of participating in the evaluation and the rest did not have enough time due to their busy schedule, which was predictable due to their intensive work schedules. Even though these four neurologists were eager to participate in our research, they mentioned their time constraint and schedule coordination issues . Thus, they were not available for Skype interviews and their evaluation took place via email. Each of them was interviewed at a distinct stage of our research and the final prototype was completely new for all of them. Therefore, they were briefed with a short introductory video [5] regarding the prototype's capabilities. A hyperlink of the final prototype was also sent to their email. The applied methodology of the design evaluation were outlined as follows:

1- Each participant was asked to watch the short video in the first place.
2- After familiarization of participants with the prototype, they were asked to open the link and interact with the web prototype and try to understand how it works.
3- Participants were asked to reply to the following questions according to their experience working with the prototype.

- Does the platform meet your expectations? If not, how can it be improved in the future?
- How was your experience using the platform?
- Do you have any feedback about it?

4- Their feedback was collected in order to be analysed.

6.5 Evaluation Findings

After receiving all the neurologists' feedback, thematically analysis was started. In the following segment, the evaluation findings are outlined. In general, neurologists, who

[5] https://drive.google.com/file/d/1VMdqMB1NAbDKFDXwJtJha9X2cE_Sx7pR/view?usp=sharing

participated in evaluation phase, were satisfied with the platform and mentioned that the web platform was quite comprehensible and would bolster their resources in order to recognise PD progression. However, they mentioned there were some issues that could be ameliorated in the final prototype. All findings regarding the evaluation can be divided into three main categories: extra required factors, visualization issues, and "nice-to-have" options.

Following issues were raised by neurologists according to the extra required factors:

- The experts mentioned to have a comprehensive diagnosis, visualization of the information on a daily basis could be also helpful. One of the neurologists stated: *"I find quite useful the scope function in which you can see the daily activity of the patient"* and the other one noted *"Will be good to be able to see daily patterns"*.
- As FOG is highly important to recognise the PD progression, it would be better to monitor and visualize this factor: *"Consider including FOG, If you can measure it, in the gait parameters is important and intuitive"*.
- Visualizing the arm swing as an effective factor in diagnosing disease progression is missing: *"Consider also including arm swing if you can measure it and also itemize by side"*.

In the following the visualization-issue solutions were suggested by the neurologists are written:

- As an abbreviation of the word "Time", we used the letter "T" in the legend of some diagrams, which was not comprehensible : *"not sure what the T at the end of the activities stands for. It might be good to spell out"*.
- Using of some interactions like clicking on the points associated to the data points was not intelligible: *"I would make the interaction with data points more intuitive, as the usability may pose an issue"*.
- Participants prefer to zoom in automatically on the charts with the mouse over: *"The platform is very easy to use, and the data is easy to check and interpret. I have no further suggestions, except that maybe it is possible to zoom in automatically by moving the mouse on each diagram, by that way the pie chart could be bigger"*.
- Moreover, they think the visualization of the average percentage of activity yearly does not make sense and it is not usable at all : *"On pie chart year is not too informative and you might need just monthly/weekly info to make informed decisions"*.

Neurologists also mentioned that some "Nice- to-have" options could be implemented to the prototype to meet potential needs.

- *"It would be great to have the possibility of downloading the data within an informative file for the patient".*
- In addition, implementing a section for potential physician notes will be helpful: *"Maybe a space where physicians can add notes to the patient would also be useful".*
- One of the participants suggested to add the gender of the patient on overview page and patient profile : *"In patient information I would add the gender as variable too".*

  All in all, the neurologists who participated in the evaluation phase believed that the prototype was understandable enough and could provide insight on gait disturbances; however, there was still room for improvement, not only from a visualization perspective but also in monitoring, collecting, and visualization of the required data.

CHAPTER 7

Discussion

7.1 Discussion

In this chapter, we will discuss the results obtained from the research, advantages of the system, and the research limitations. As it was described at the beginning of the thesis, this work has two different aims. The first aim of this project was to perform user research with neurologists, to understand their needs to assess Parkinson's patients' gait disturbances and the second aim was to create a visualization that enable neurologists to understand the data that was collected passively by patients. To make the design more comprehensible, various interviews with visualization experts were also conducted to evaluate and improve the prototype from their perspective. The focus of this work was just on gait issues and monitoring and visualizing other symptoms was out of scope of this research.

The basis of the prototype was built upon the literature search and the rest was based on the conducted interviews with two groups of participants, respectively, neurologists and visualization experts.

The initial aim of this project was deduced by performing interviews with neurologists who outlined the most vital factors in understanding and monitoring PD progression. Based on the collected results from the interviews with neurologists stride length, gait speed, number of falls, freezing of gait, general patients' activities, and posture of the patients were considered as the imperative factors in order to evaluate patients' gait disturbances. As the smartphone was not able to monitor all these factors- due to lack of monitored data- only requirements such as stride length, gait speed, number of falls, and percentage of patients' different activities were visualized. As a result, freezing of gait and patients' postures were not implemented in the final prototype. Besides the neurologists' required factors to evaluate gait issues, other information was gleaned in order to improve the prototype and monitoring system which is discussed in this chapter.

The second aim of this work was visualization of neurologists' requirements. There is no doubt that developing a web platform in a medical field is not straightforward and deemed as a complex task. Different aspects such as human computer interaction, usability issues and characteristics of the users should be considered to design a proper tool. It is noticeable that proper use of visualization techniques makes data comprehension and comparison easier [64]. Therefore, in order to have an acceptable platform, it should meet physicians' specifications and it is essential that it has appropriate data visualization.

It is noteworthy that the prototype being analyzed by visualization experts, was effective and it enabled better user interaction and comprehension. Although neurologists are the target group of the system and must have declared the key factors required, they did not have visualization knowledge; and the improvement of the prototype without involving visualization experts was not possible and would not yield comprehensive results.
In the following segment, some of the research results are highlighted.

One of the key concerns of the neurologists was according to time issues. They prefer to use a simple system that is not time-consuming and could provide their real needs in the most explicit way. Therefore, their concern was considered during the development of the prototype, and an attempt was made to create an uncomplicated visualization.

The interviews were performed with different neurologists with different age ranges. During this research, we understood that most of the older neurologists refused to use new technologies to evaluate PD and they believe it to be time-consuming if they were to use the web platform. Hence, they were more lenient towards the use of traditional methods in order to identify the disease progression. In contrast, the younger neurologists welcomed the system and were keen on utilizing it.

Since neurologists were in three different countries such as Austria, Spain and Portugal, we could verify whether the project would be acceptable in different communities with different facilities and cultures. Feedback gained from the participants proved that they welcome the system and the general satisfaction was quite positive. However, they had some concerns regarding using the web platform and mentioned the following challenges.

The neurologists N1 and N3 mentioned that they are not completely confident to evaluate PD solely based on the results obtained from our system. They all supposed that "Trust" is an issue while using this web platform. For instance, as we have a lot of "No activity" value in our visualization, which could be related to the time that the device did not gather data due to various reasons such as lack of battery or patient forgetfulness ,the information could be rendered useless. The higher "No activity" value, the less trust they would have in the system due to lack of proper data. Furthermore, one of the neurologists stated that the location of the smartphone is considered as a challenge and might influence the quality and competence of the gathered data. However, researchers could not still understand which part of the body the best part is to locate the sensor to gather more reliable information [64].

Moreover, they mentioned a wide range of Parkinson's patients are elderly people, hence, they might not have smartphones to gather the information or even dislike carrying it all the time. Therefore, even if the best visualization is implemented, if the user does not carry their smartphone, the web platform becomes inconsequential [65] cited in [66]. Consequently, some neurologists stated that smartphones are not medical devices at least from a physicians' perspective and also smartphones could have battery issue.

The neurologists N2 and N7 agreed that one of the points that needs to be utilized in our visualization is having a normative value about gathered data such as step length and gait speed in order to compare patient's information with it. They additionally mentioned various factors such as the patient's age, gender, height and weight can influence the gathered information. For example, none of the neurologists knew the difference between the step length of a 50 years old woman and 70 years old woman with different heights. Thus, they need the normative value to set a basis for comparison. According to our knowledge, no normative values exist that are based on the age, gender, height and weight of the patient which could provide accurate information about factors visualized in our research. Therefore, this point is considered as one of the key challenges of this visualization.

All things considered, the final visualization has many positive capabilities. As it was described in section 6.4 the evaluation phase was conducted by the younger neurologists, because they were the only group who replied to our email and were interested in participating in the evaluation phase. The final prototype was highly appreciated amongst neurologists who participated in the evaluation phase. They liked the idea of monitoring symptoms and visualizing it and they find it helpful for recognizing PD progression. Participants claimed that the final prototype was understandable even without watching the introduction video and they deemed it as one of the key strengths of the system.

Also, they claimed that they could not ignore the advantages of this system and visualization of the symptoms. Undoubtedly, using this system, facilitates the evaluation of PD. In the following, some possible advantages of the system based on neurologists feedback are highlighted:

- Providing accurate insight about gait issues
- Providing the better insight of the disease progression
- Possibility to make accurate adjustment to medication due to visualizing the patients symptoms during their daily life
- Saving neurologists time by eliminating the time of clinical assessments

To sum up, developing and analysing the prototype from two different perspectives, is one of the key hallmarks of this research and leaded to creation of a prototype which is self- explanatory and understandable with the target group.

7.1.1 Limitations

Like any other research, we also faced some limitations according to our research. The results derived from interviews were extremely important, because we generalized the result to the whole target group. However, as it was too difficult to find neurologists who were eager to participate in our research, we just conducted interviews with seven neurologists and the evaluation was conducted with four of them. Hence, the sample size of the interviewees was small and as the time of this research was limited, we could not seek more neurologists. The low participation numbers may decrease the reliability of the system. In other words, as we have a specific target group, it would be better to perform interviews with as many as possible neurologists and then we can apply the generalizations to the whole target group. Additionally, all interviews with neurologists, except one of them, performed via Skype which made us unable to view how they are interacting with the platform. This hindrance might have had an influence on analysing the interview findings. As gathering real data takes time, in our research we used data relating to four months and we extended the data to one year. Thus, we have repetitive data in our visualization which prevents the data from appearing realistic. If the collected data was collected over a year, the visualization could look more real. Furthermore, Although the focus of this work was just on gait issues, our system was not able to detect FOG and it was one of the key challenges of the system. Moreover, neurologists pointed, to make a right decision about disease progression, they need to be aware of other factors such as the patient's posture and balance. Due to the limitation of the smartphone for gathering data about these factors, some of the neurologists' requirements have not been implemented. For this reason, it is important to keep in mind that we can not claim that we implemented all neurologists' needs.

At the end of this discussion, we should point out that according to the literature search and interviews with neurologists, it is highly pragmatic to provide accurate and objective information about Parkinson's patients symptoms for neurologists. Despite the fact that exceptions exist and some older neurologists are not eager to use these kinds of systems, most of them appreciate the system.

CHAPTER 8

Conclusion and Future Work

8.1 Conclusion

Nowadays a variety of wearable and non wearable devices have been devised that aid in monitoring the patients' symptoms and to provide objective information for neurologists. In this thesis, a UCD process was conducted in order to create a prototype that could assist neurologists to be informed about PD's symptoms. The focus of this visualization was just on the gait disturbances.

Initially, it was essential to distinguish the most important factors which correlated to the disease progression from a neurologists' perspective. The results gained from the interview with neurologists are highlighted in the table 5.2. Various iterations of the prototype which can be found in appendix C were created and evaluated through interviews with neurologists. Subsequently, various interviews with visualization experts were conducted in order to assess the prototype from their point of view and to resolve issues that posed a problem. Implementation of the final prototype is described in chapter 6. In the following segment, are the potential of the improvement of this work in the future will be highlighted.

8.2 Future Work

In this section, we will describe the steps that could be taken for future augmentation of the prototype. Although the focal point of our work is understanding the required factors in order evaluate PD progression and visualization of gait issues, we must not ignore the fact that our visualization is directly related to the data collected by smartphone, and if the factors required by doctors are not collected by the smartphone, the quality and acceptability of the prototype will also be affected. All neurologists, who participated not only in the design process, but also in the evaluation phase, adduce that one of the key factors to evaluate PD is FOG. Despite the visualization being in accordance with gait issues and FOG is considered as an important gait issue, however, we could not visualize this factor because our system is not apt to collect data regarding FOG. We believe that there is a lot of room for improvement and overcoming this challenge in the future in order to create a system that can monitor not only FOG but also patient posture like arm swings. By gathering data from different parts of a patient's body, more factors can be visualized and interpreted by neurologists to facilitate making a perfect decision.

In terms of prototype visualization, some additional features could be visualised based on results driven from evaluation, such as the ability to zoom in and out in each chart, ability to annotate each patient's profile in addition to the list medications taken by the patient. Moreover, the patient profile could be completed and some extra specifications like gender could be added to it.

One of the most important aspects which should be implemented and supported in the future installment is providing a normative value for each patient. Enabling neurologists to compare patient's monitored data with normative values.

Another possible option would be gathering information related to more patients. Thus more patients information can be visualized and more potential visualization challenges might be addressed.

Since the time of this research was limited, we could not interview a lot of neurologists and visualization experts. For the further development of the prototype, more interviews could be conducted to get a better insight into requirements.

All in all, in each research there is always room for advancement and our research could be useful as a foundation for other research.

APPENDIX A

Consent Forms

A.1 Neurologists Informed Consent

Fraunhofer PORTUGAL

TECHNISCHE UNIVERSITÄT WIEN Vienna University of Technology

CONSENT FOR PARTICIPATION IN RESEARCH STUDY

Association Fraunhofer Portugal Research and *Vienna University of Technology (Technische Universität Wien)* are working on a research project entitled Co-design of a web platform for visualizing Parkinson's gait symptoms. The project has the goal to understand how specialists evaluate gait issues and to co-design a web application to visualize gait-related parameters of patients. We would like to count on your participation to help us reach these goals. You would participate in an interview where we will collect demographic data, insights on how you evaluate gait in your practice, and your perspective on remotely monitoring gait of patients with Parkinson's. Moreover, with your permission, the conversation will be audio-recorded to be analysed later.

The participation in this study does not present any risk to participants' physical or mental integrity, does not involve any loss or material damage and does not involve any payment whatsoever.

The data being collected are confidential and shall only be used by the researchers towards the originally intended ends. The data collected cannot be traced back to the owner. *Association Fraunhofer Portugal Research* and *Vienna University of Technology* will take all the necessary measures to safeguard and protect the collected data in order to avoid access from unauthorized third parties.

Your participation in this study is voluntary and you are free to withdraw from it at any time with no consequence whatsoever.

We very much appreciate your contribution, which is crucial to our research.

The participant:

I declare to have read and understood this document, as well as the oral information that I was given and I accept to take part in this research. I allow the use of the data which I provide on a voluntary basis, trusting that they will only be used for this research and with the guarantees of confidentiality and anonymity that I am being given by the researcher. I authorize the anonymous communication of the data and tests results to other entities who establish partnerships for research purposes with Association Fraunhofer Portugal Research and Vienna University of Technology, as well as in meetings, scientific journals and academic papers.

Name: ____

Signature: ____ Date ___ / ___ / ______

Main researcher: Niloufar Chakhmaghi, e1576007@student.tuwien.ac.at

Supervisor at Fraunhofer: Francisco Nunes, francisco.nunes@fraunhofer.pt,

Supervisor at TU Wien: Geraldine Fitzpatrick, geraldine.fitzpatrick@tuwien.ac.at

THIS DOCUMENT IS MADE IN DUPLICATE: ONE FOR THE PARTICIPANT AND ONE FOR THE RESEARCHER. 1 / 1

Figure A.1: Page 1

A.2 Visualization Experts Informed Consent

CONSENT FOR PARTICIPATION IN RESEARCH STUDY

Association Fraunhofer Portugal Research and Vienna University of Technology (Technische Universität Wien) are working on a research project entitled Co-design of a web platform for visualizing Parkinson's gait symptoms. The project has the goal to understand how medical specialists evaluate gait issues and to co-design a web application to visualize gait-related parameters of patients. We would like to count on your participations to help us reach these goals. At this point, we have designed a web platform which can visualize the factors that are important for medical specialists to assess the Parkinson's disease progression. You will participate in an interview where you will evaluate the visualization of the pre designed web platform and help us to understand the visualization weaknesses and improve them to make it more understandble. Moreover, with your permission, the converstaion will be audio-recorded to analysed later.

The participation in this study does not present any risk to your physical or mental integrity, does not involve any loss or material damage and does not involve any payment.

The data being collected are confidential and will only be used by the researchers towards the originally intended ends. The data will also be anonymised so that it cannot be traced back to the owner. *Association Fraunhofer Portugal Research* and *TU Wien* will take all the necessary measures to safeguard and protect the collected data in order to avoid access from unauthorized third parties.

Your participation in this study is voluntary and you are free to withdraw from it at any time with no consequence whatsoever.

We very much appreciate your contribution, which is crucial to our research, and hopefully in the longer term to improving the delivery of medical care for people with PD.

The participant:

I declare to have read and understood this document, as well as the oral information that I was given, and I accept to take part in this research. I allow the use of the data which I provide on a voluntary basis, trusting that they will only be used for this research and with the guarantees of confidentiality and anonymity that I am being given by the researcher. I authorize the anonymous communication of the data and tests results to other entities who establish partnerships for research purposes with Association Fraunhofer Portugal Research and Vienna University of Technology, as well as in meetings, scientific journals and academic papers.

Name: ______________________________

Signature: ____________________________ Date ___ / ___ / _____

Do you like to receive the thesis report? If yes, please write your email Address here.

____

Main researcher: Niloufar Chakhmaghi, e1576007@student.tuwien.ac.at

Supervisor at Fraunhofer: Francisco Nunes, francisco.nunes@fraunhofer.pt,

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Figure A.2: Page 1

Fraunhofer PORTUGAL

TECHNISCHE UNIVERSITÄT WIEN Vienna University of Technology

CONSENT FOR PARTICIPATION IN RESEARCH STUDY

Supervisor at TU Wien: Geraldine Fitzpatrick, geraldine.fitzpatrick@tuwien.ac.at

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Figure A.3: Page 2

A.3 Patient Informed Consent

CONSENT FOR PARTICIPATION IN RESEARCH STUDY

Association Fraunhofer Portugal Research and TU Wien (Technische Universität Wien) are working on a research project entitled Co-design of a web platform for visualizing Parkinson's gait symptoms. The project has the goal to understand how medical specialists evaluate gait issues and to co-design a web application to visualize gait-related parameters of patients. To make this work most useful, it is important to have access to some real data from people with PD about activities during their daily lives. You would help us enormously if you were able to contribute some of your activity data for our study.

Specifically, we will ask you to gather data about your daily activities and your symptoms for us. This can be done easily and passively by putting your mobile phone in your pocket during your daily life you can gather our intended information. Afterward, we will use the collected data as the main source for programming and visualizing the intended web platform. As you are contributing to the design of a future system, your participation in this research is not part of your formal care and so you will not receive any feedback about your care. However if you are interested in a report of the thesis work we will share that with you.

The participation in this study does not present any risk to your physical or mental integrity, does not involve any loss or material damage and does not involve any payment.

The data being collected are confidential and will only be used by the researchers towards the originally intended ends. The data will also be anonymised so that it cannot be traced back to the owner. *Association Fraunhofer Portugal Research* and *TU Wien* will take all the necessary measures to safeguard and protect the collected data in order to avoid access from unauthorized third parties.

Your participation in this study is voluntary and you are free to withdraw from it at any time with no consequence whatsoever.

We very much appreciate your contribution, which is crucial to our research, and hopefully in the longer term to improving the delivery of medical care for people with PD.

The participant:

I declare to have read and understood this document, as well as the oral information that I was given, and I accept to take part in this research. I allow the use of the data which I provide on a voluntary basis, trusting that they will only be used for this research and with the guarantees of confidentiality and anonymity that I

am being given by the researcher. I authorize the anonymous communication of the data and tests results to other entities who establish partnerships for research purposes with Association Fraunhofer Portugal Research and Vienna University of Technology, as well as in meetings, scientific journals and academic papers.

Name: ____________________________________

Signature: ____________________________________ Date __ / __ / ____

Do you like to receive the thesis report? If yes, please write your email Address here.

____

THIS DOCUMENT IS MADE IN DUPLICATE: ONE FOR THE PARTICIPANT AND ONE FOR THE RESEARCHER. 1 / 2

Figure A.4: Page 1

Fraunhofer PORTUGAL

TECHNISCHE UNIVERSITÄT WIEN Vienna University of Technology

CONSENT FOR PARTICIPATION IN RESEARCH STUDY

Main researcher: Niloufar Chakhmaghi, e1576007@student.tuwien.ac.at

Supervisor at Fraunhofer: Francisco Nunes, francisco.nunes@fraunhofer.pt,

Supervisor at TU Wien: Geraldine Fitzpatrick, geraldine.fitzpatrick@tuwien.ac.at

THIS DOCUMENT IS MADE IN DUPLICATE: ONE FOR THE PARTICIPANT AND ONE FOR THE RESEARCHER. 2 / 2

Figure A.5: Page 2

APPENDIX B

Interview Guide

- Age
- Years of experience as a neurologist

Aim 1: Explore Context

1 - Could you tell me a bit about what your work?
2 - Could you describe me the last consultation you had with a Parkinson's patient?
3 - What kind of data is important to evaluate gait-related issues?
4 - How do you keep track of the symptoms of a patient?
5 - How do you know if a person improved from one consultation to another?
6 - How do you recognize the ON and OFF phase of Parkinson's disease?

Aim 2: Role of Technology

We are developing a mobile system for patients to use in ambulatory. The idea is that patients wear the system passively and that it monitors their condition.
1 - What do you know about monitoring patients during their daily lives and visualization of this collected data?
2 - Imagining that you would like to monitor the gait of the patients, what would be the most important metrics to record?
3 - Can you give me some examples of successful technologies to support clinical decision making? What makes them good examples?

Aim 3: Recognise the obstacles

1 - Do you have any experience about using a web platform, which could visualize Parkinson's Patients symptoms during their daily life? If yes, what kind of negative and Positive experiences you have?
2 - Do you foresee any issue in a system that monitors gait with a smartphone in the pocket?
3 - What are the challenges for neurologists to use a web platform to be informed about patients' daily lives?
4 - Could you name some positive and negative outcome of modifying the prescription plan and evaluating Parkinson's remotely?

Aim: Introduce the initial Prototype and ask them about

1 - When you look at the first diagram, what kind of info are you looking for?
2 - What can you understand from the first diagram?
3 - Does it meet your expectations?
4 - if not, how is it the different from what you expected?
5 - What can you understand from the second diagram?
6 - Does it meet your expectations?
7 - If not, how is it the different from what you expected?
8 - How about the last table? Does it meet your expectations? Why?

APPENDIX C

All Prototype Iterations

C.1 First Iteration

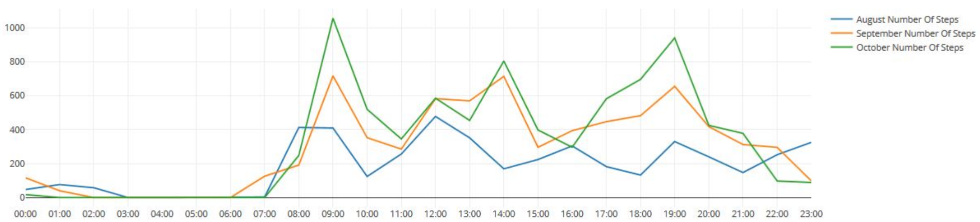

Figure C.1: Visualization of hourly average of number of steps in 3 different individual month

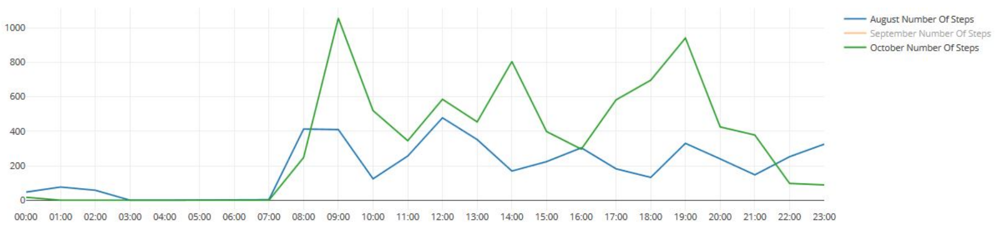

Figure C.2: Visualization of hourly average number of steps while data according to September is deselected

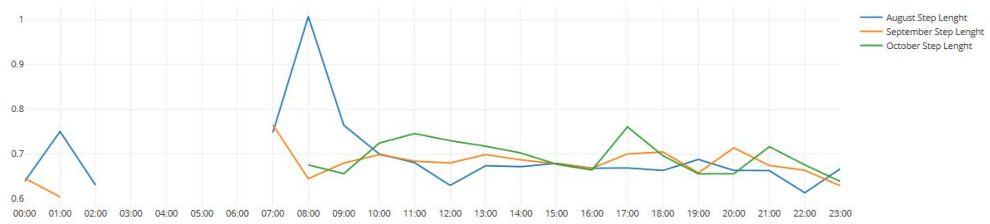

Figure C.3: Visualization of hourly average of step length in 3 different month

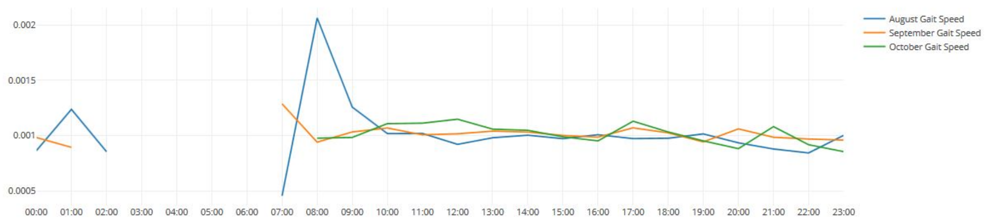

Figure C.4: Visualization of hourly average of gait speed in 3 different month

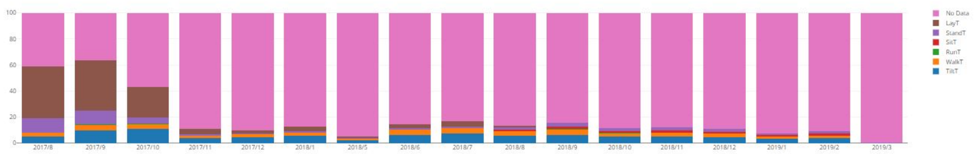

Figure C.5: Visualization of monthly average percentage of various activities

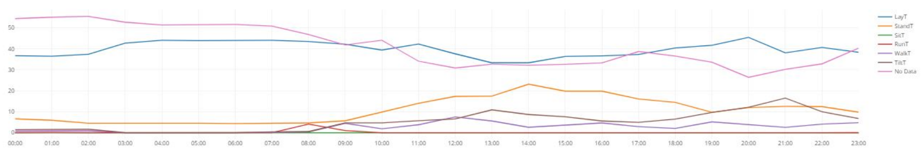

Figure C.6: Visualization of hourly average percentage of various activities

C.2 Second Iteration

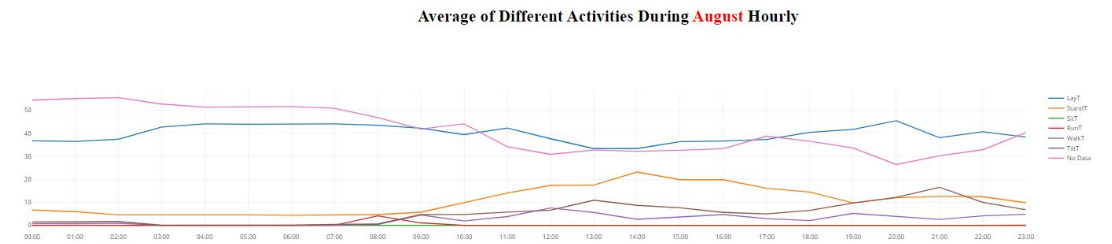

Figure C.7: Visualization of hourly average of different activities in August

Figure C.8: Hourly average of step length in 3 individual months

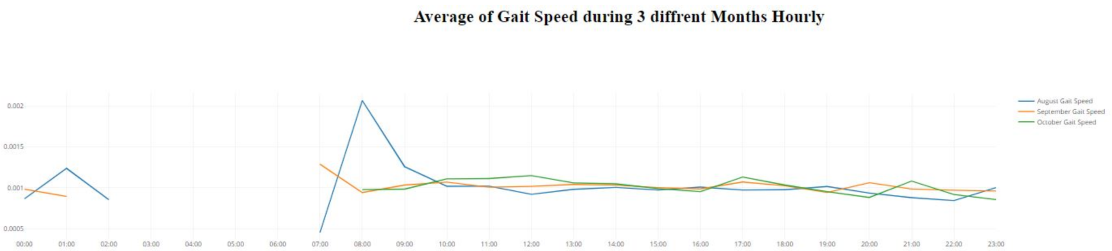

Figure C.9: Hourly average of gait speed in 3 individual months

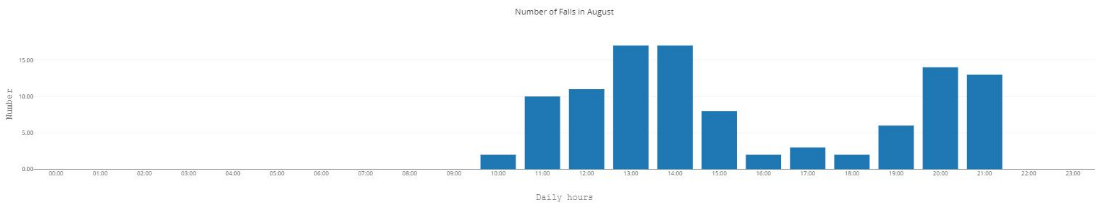

Figure C.10: Number of falls in August hourly

C.3 Third Iteration

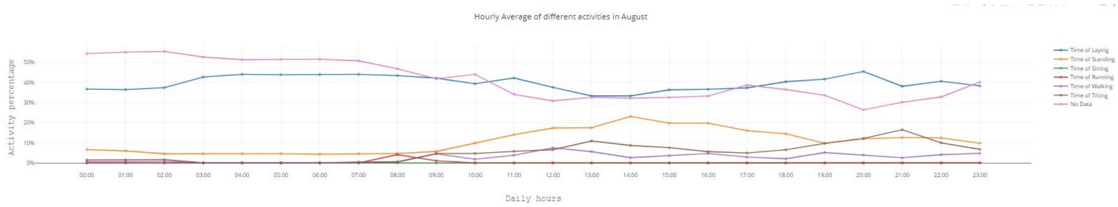

Figure C.11: Visualization of hourly average of different activities in August

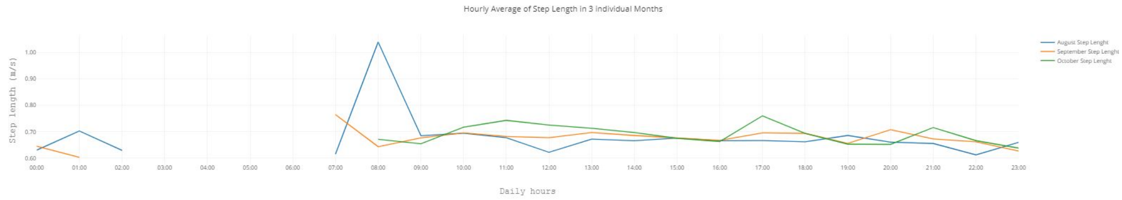

Figure C.12: Hourly average of step length in 3 individual months

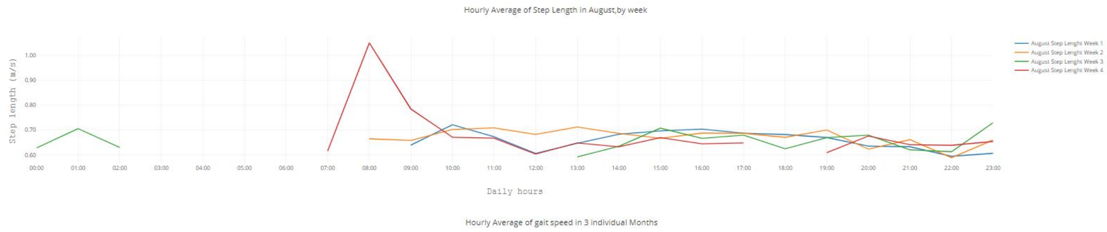

Figure C.13: Hourly average of step length in August, by week

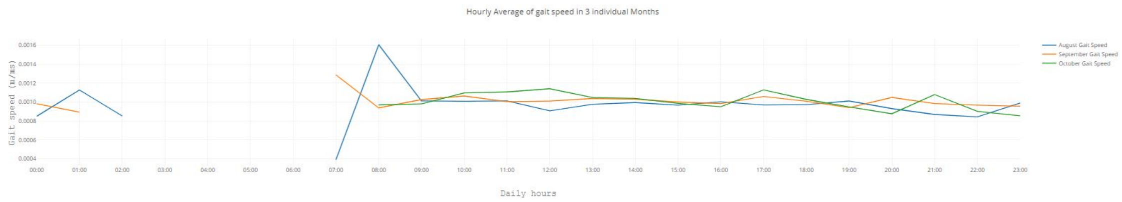

Figure C.14: Hourly average of gait speed in 3 individual months

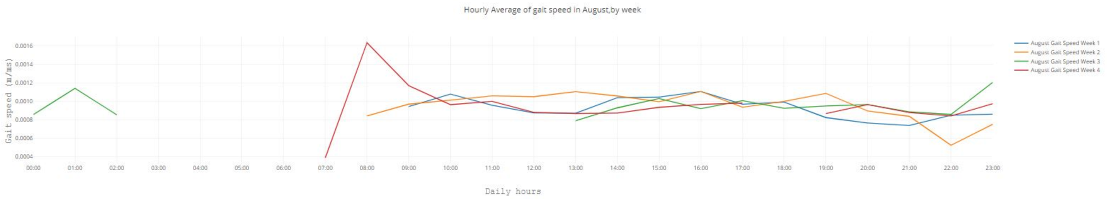

Figure C.15: Hourly average of gait speed in August, by week

C.4 Fourth Iteration

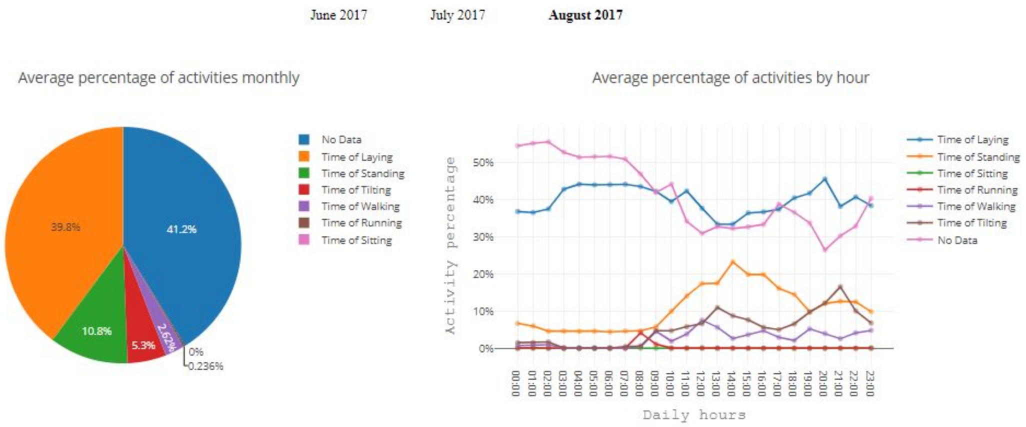

Figure C.16: Left: visualization of average percentage of activities monthly. Right: visualization of average percentage of various activities hourly

Figure C.17: Visualization of hourly average of step length in 3 individual months

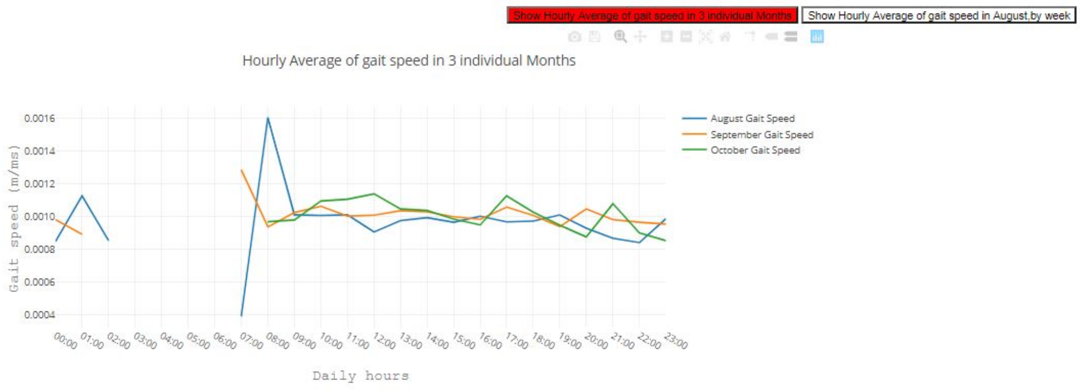

Figure C.18: Visualization of hourly average of gait speed in 3 individual months

Figure C.19: Visualization of number of falls in August, hourly

C.5 Fifth Iteration

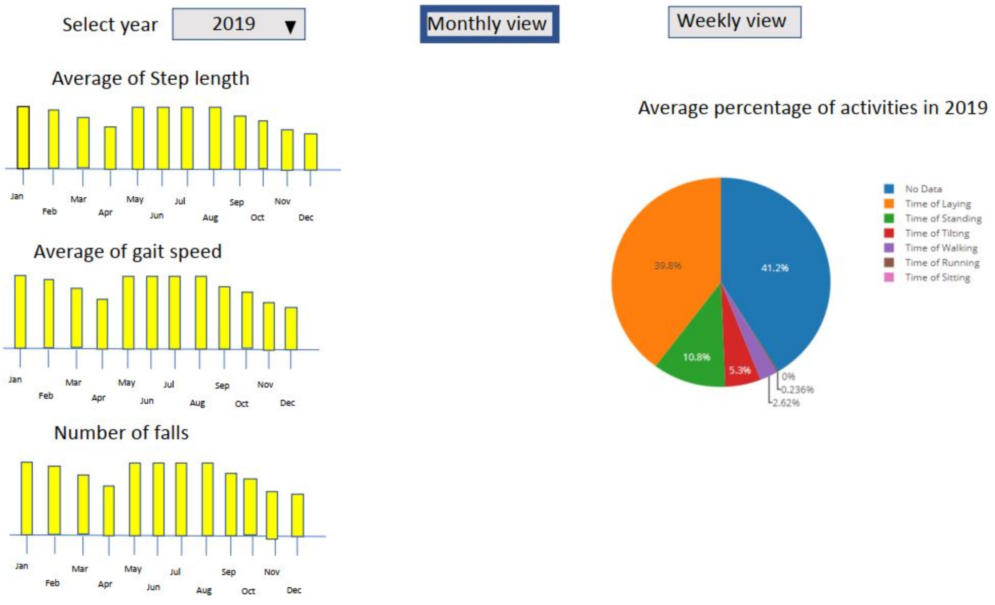

Figure C.20: Visualization of overview page

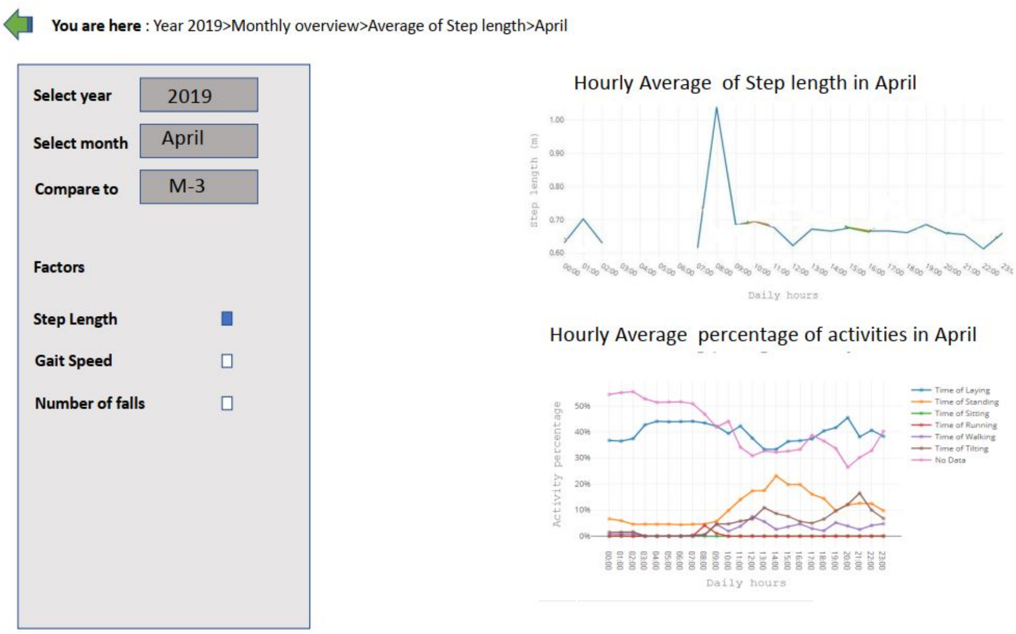

Figure C.21: Visualization of detail page

List of Figures

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Acronyms

EMG electromyography sensors. 11

FOG freezing of gait. 8, 11, 12, 35, 67, 72, 74

IMU Inertial Measurement Units. 12

PD Parkinson's disease. 3–5, 7–13, 15, 18, 22, 25, 26, 32, 33, 51, 57, 67, 69–71, 73, 74

PWP patient with Parkinson's. 13

QOL quality of life. xi, 9, 10

UCD User-centred Design. 17, 73

UPDRS Unified Parkinson's Disease Rating Scale. 10

WSFRSA Wearable shoes fused with range sensor arrays. 12

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