



FACULTY OF INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING

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**TRACK MYSELF: A SMARTPHONE-BASED
TOOL FOR MONITORING PARKINSON'S
DISEASE.**

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ABSTRACT

Parkinson disease (PD) is a fast-spreading neurological disorder that affects millions of people worldwide, it hinders its patients from performing daily activities with ease. Its symptoms may vary within hours and progress differently for each patient, and usually assessed clinically every six months. It requires customized treatment plan for each patient and demands adherence of patients to complex medication regimens. The goal of this thesis is to design, implement, and test a mobile app named “Track Myself” that can help people with Parkinson’s disease (PwP) resolve these issues. The app has two components that help PwP assess their symptoms level regularly, the first component is an accelerometer-based game that detects the patient’s hand movement and calculate a score for its accuracy, the second component is a self-report symptoms survey filled by the patient every day to rate their severity level. A medication journal is implemented in the app for the patients to log their medication intakes regularly, which are prescribed by their doctors using the app as well, this help keep track of the medication history and calculate the patient’s medication adherence. The app also contains a dashboard made of three charts, representing the medication time-adherence, symptom surveys, and game scores of the patient. The purpose of this dashboard is to help the doctors form relationships between the data in the charts and determine the best future treatment plan. The app was tested for two weeks by ten healthy participants, they were asked to act in the persona of a PD patient and perform certain tasks, where information about the disease and experiences of actual patients were provided for these participants. A questionnaire was sent to the participants after the study, it consists of open-ended questions, rating statements, as well as a validated mobile health app usability questionnaire (MAUQ). The participants rated the app as easy to use for PwP in most features with mean score of 6.04/7 and perceived the app as very useful in helping PwP with mean score of 6.18/7. Source code links are available in Appendix 4.

Keywords: Parkinson’s disease, accelerometer-based game, medication journal, dashboard, usability.

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FOREWORD

This research has been financially supported by Academy of Finland 6Genesis Flagship (grant 318927), STOP (grant 313224) and GenZ (grant 318930). Also, the thesis was sponsored by the Center of Ubiquitous Computing (UBICOMP) at the University of Oulu, and I would like to thank our research unit for the support. Also, I would like to thank my supervisors Prof. Denzil Ferreira and technical supervisor MSc. Elina Kuosmanen for their continuous help they provided me, starting with forming the topic and during the practical work. Also, I want to thank the participants that helped in the evaluation process of the app.

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LIST OF ABBREVIATIONS AND SYMBOLS

API	Application programming interface
APK	Android Package
EDPA	European Parkinson's Disease Association
JSON	JavaScript Object Notation
MAUQ	mHealth App Usability Questionnaire
PD	Parkinson's disease
PwP	People with Parkinson's disease
SDK	Software Development Kit
STOP	Sentient Tracking of Parkinson's
UI	User interface

1. INTRODUCTION

Parkinson's disease (PD) is a neurological disorder that handicap the lives of millions of people worldwide and the number of patients is increasing. It hinders the daily activities of its patients, and it affects their physical, and mental health. People with Parkinson's disease (PwP) suffer from motor symptoms like tremors, rigid limbs, and slow movements [1]. Mental and behavioral symptoms arise in progressive disease phases [2]. Symptoms vary from a patient to the other, while also varying within hours, making it hard to assess its severity level [1][3]. However, clinical assessments usually happen only twice a year [1]. Therefore, a more close and frequent method is in need to assess symptoms of PwP. Technology can have a role in solving this problem, however, a lot of the ideas made are either confusing to use for PwP or disrupt their daily routines [1]. So, this introduces the first research question,

RQ1: How to keep track of PD symptoms using a smartphone?

The first research question aims at finding some methods that can be used to regularly detect the specific symptoms each PD patient has and their severity. These methods need to be present in a mobile application, that is engaging and easy to use by PwP. A literature review will be made to find more about previous approaches.

The disease treatment is also difficult as there is no common treatment that work for all the patients [3]. Moreover, treatment requires complicated medications collections that fit each patient [3], where adherence to these medications is strongly needed for the best results [4]. However, patients are not adherent to their medications half the times [4][5] for different intentional or unintentional reasons [6].

Therefore, the patients' medication history and adherence level need to be recorded in an organized way to detect any adherence issues and enhance the treatment results. Instead of using pen and paper to write down patients' medication behavior, technology can be used for to solve this point. An e-diary proved to be a reliable method for collecting medications data for patients taking dense medications. [7][8].

RQ2: How to track medication adherence for PwP using a smartphone?

The second research question focuses on finding a method to keep track of different kinds of medications taken by the PwP throughout the day in order to calculate their adherence to them. These methods need to be present in the same mobile application mentioned above, with good interface that is suitable to use by PwP.

Now that we have some methods to detect each patient's specific symptoms and their severity, as well as data for the medications' intake for the patient, there is a

possibility to make use of all the data collected. Doctors can make relations between medications adherence and symptoms progress, thus, help determining the best future treatment plan for every patient. Especially because treatment regimen needs to be customized according to every patient's symptoms forms and severity. To make relations between all these data and emphasize important points, they should be presented in graphs [9]. Showing multiple graphs can help the viewer make conclusions between these graphs, a dashboard is a suitable platform to visualize these graphs in a useful and understandable way, by following some general design rules for dashboards [10].

RQ3: How to visualize the data collected by the app?

The third research question refers to making use of the data the app collected by visualizing them in a practical and well-designed platform, in order to benefit both the patients and doctors.

The main focus of the thesis is to design, implement and test a mobile app named "Track Myself" that aims at solving the previous challenges. In this thesis, chapter 2 introduces the related work of various ideas that can benefit PwP. Chapter 3 focuses on design guidelines that were considered for the app. Chapter 4 presents the tools used in the design, implementation, and testing processes of the app. Chapter 5 explains the implementation of the app features in detail. Chapter 6 covers the evaluation study made on the app. Chapter 7 is a discussion of the app, its limitations, and future work. Chapter 8 presents the conclusion of the thesis.

2. RELATED WORK

2.1. Parkinson's disease

Neurological disorders are now the leading source of disability worldwide, and the fastest growing neurological disorder in the world is Parkinson disease [11]. Parkinson's disease is a developing neurological disorder affecting the movement and body functionalities of humans, it affects both the mental and physical conditions of its patients. Parkinson's Disease affects around ten million people worldwide [1].

Patients with this condition develop a group of symptoms that decrease their quality of life. Some of its physical symptoms can be tremors, slower and limited body movements [1]. Rigidity, when muscles are not able to relax, is a very common disease symptom as well [12][13]. Non motor symptoms can include anxiety, depression, and even visual hallucinations [13]. It even causes some psychological changes in the patient's routine [1].

Historically, PD has been a rare disorder, however, PD is now becoming almost a pandemic that requires better planning, and creative approaches [11]. From 1990 to 2015, the number of PwP has doubled. Driven principally by aging, this number is projected to double again to be between 12-17 million by 2040 [11]. According to the European Parkinson's Disease Association (EPDA) [12], the symptoms of this disease usually progress slowly, and unfortunately irreversible. At first, symptoms usually appear in motor functions, while in more advanced stages, symptoms can be behavioral or mental related [2].

According to Vega et al. [1], its traditional clinical review usually happens every six months and it mostly depends on manual expertise, while one problem in PD's assessment is that its symptoms vary within hours, and that is why the traditional visits are not fully precise. Therefore, a detailed model of how these symptoms change is needed by the doctors to follow up on each patient's condition and tailor their medications accordingly, which in turn, should reduce the impact of the symptoms on the patients' daily life routine and thus enhancing their quality of life. Some technology approaches were tried on the patients to help solve the wrong symptoms assessment problem, however, most of these approaches disrupt patients' routines or are hard to use [1]. Technological approaches in monitoring the symptoms include accelerometers, magnetic motion trackers, digital drawings [14].

There is still no common treatment method for all the patients despite the high number of PwP [3]. According to Sharma et al. [3], PD treatment is challenging also because PD progresses distinctively from one patient to another, therefore successful management of PD requires complex medication regimens specifically chosen according to each individual's needs. These changing symptoms make it hard for the

physician to prescribe a better medication regimen during the short available visit time [3].

2.2. Gamification to monitor PD

Gamification is a casual term for utilizing some game features to be used in non-gaming systems [15]. This improves the user experience and increase user engagement in services and applications that not related to games [15]. Therefore, it is beneficial if gamification is applied to help PwP, either in assessing their symptoms or even help them in their treatment. For example [16], with the help of some PwP and physiotherapists, designed 5 games that can be played by PwP, and they proved to make them enjoy their exercise routines in the form of games, especially because most traditional games are harder for the patients. The authors of [17] also tried an Xbox video game console on PwP and was noted to be of good assistance to rehabilitation.

For PD symptoms assessment, many studies show that gamification can be used as a good assessment method and substitute the traditional methods, for example, authors of [18] designed a virtual reality game using Unity3D, where the game shows virtual movement targets, and the player should use a haptic game controller to catch these falling objects, and quantitative data representing the patient's movement is collected. According to the study the authors conducted, it proved it can be used for quantitative assessment of the PD symptoms, while also motivating the patients to monitor their health condition. However, this is rather a complex game to implement for the scope of the app.

Another approach also was a mobile app developed by [19], that captures the movement acceleration of the patients while performing an exercising task. The smartphone is fixed to the hand or ankle of the patient with a strap, and the screen shows some instructions for the task. The game has multiple exercises, like hand stability, walking, and turning exercises.

In a study by Politis et al. [20] PD patients were asked to rank their most troublesome symptoms during the last 6 months. Tremors were the second most reported motor symptom in PD early stages, and the most reported motor symptom in PD later stages. A study on 17 real PwP demonstrated the reliability of a quick test using smartphone accelerometer signal to indicate tremor, that can give quick tremor diagnosis information for the clinician [21]. Also, it has been shown in a study by Kuosmanen et al. [22] with actual PwP, that the accelerometer sensor signal can act as a systematic tremor severity assessment method. Also, in another study by LeMoyne et al. [23], an iPhone wireless accelerometer application proved to have the ability to quantify Parkinson's disease tremor characteristics. These studies

emphasize the benefits of measuring the tremor level using the smartphone accelerometer sensor.

A suitable mobile game to assess the level of PD symptoms was implemented in the “STOP” mobile application [24] shown in Figure 1. The goal of the game was to balance the smartphone of the player horizontally facing upwards, in order to keep a ball in the center of the screen for 10 seconds, and the score depends on how close to the center the ball stays during these 10 seconds. The tremor symptoms of PD can prevent the user from keeping the ball centered, and this should indicate the symptoms level of the patient. A study was conducted on this game for 1 month with 13 real PwP aged between 52 and 73 years old, the participants were asked to play the game at least four times every day during the study period. The game assumed that tremor among all of the motor symptoms had the biggest effect on the game score. The study reported the game as effortless to integrate to the daily routine of the patients, but one participant reported the game as repetitive and boring. According to the study, the authors report that the game scores did not reflect the user estimation of their symptom level. The paper justifies the poor correlation to not using the accelerometer data collected to calculate the score, which can be a good indicator for the tremors, but rather using only the distance of ball deviation from the center in relation to the whole screen [22][24].

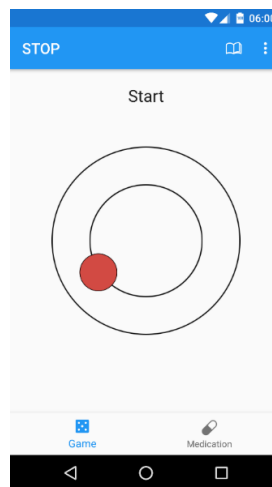


Figure 1. Ball game interface of STOP app [25].

2.3. Symptoms self-reporting

According to the world health organization’s international classification of impairments, disabilities, and handicaps 1980 [26], reporting the impact of a disease on daily activities is an important measurement for any disease state. Most likely, how the disease hinders the patient’s normal life is more important to the patient than

the official severity level of a disease. Furthermore, self-report of the operational status can be used to monitor and evaluate new therapies.

A self-rating scale was created by Mischley et al. [27] to allow PwP to report their symptoms severity, its goal was to measure the disease level without requiring a clinical exam, taking only a few minutes to complete, and capturing both motor and non-motor PD symptoms that affect the quality of the life the most. This scale is called the “Patient Reported Outcomes in Parkinson’s Disease” (PRO-PD) and is calculated based on the score of 32 slide bars, where each slide bar evaluates a common PD symptom (like slowness, falling, etc.). The PRO-PD has been used in three studies to measure the PD symptoms severity, and data of 1031 participants in total was available for analysis from these studies. Fatigue and impaired handwriting were the most repeatedly reported symptoms, where patients suffering from PD for longer durations tended to report more severe symptoms.

Also, Hobson et al. [28] managed to develop a brief, valid and reliable self-report scale for the assessment of PwP daily activities. This scale is called “Parkinson’s Disease Activities of Daily Living Scale” (PADLS). PADLS assessment survey contains 5 descriptions, and the patient should choose one of them that best describes how PD has affected their daily activities. These descriptions start from “No difficulties with day-to-day activities” to “Extreme difficulties with day-to-day activities”. PADLS was validated and reliably tested by 2 testing groups, the first is 38 PwP, followed by another 132 PwP aged over 60 years old. PADLS was found to be a valid and reliable method to assess PD severity and quality of life through self-report, and complements existing PD clinical measuring practices.

An example of an app that used symptoms self-reporting for PwP is the Parkinson’s tracker app made by Lakshminarayana et al. [29], it consists of a sliding petal interface that can be used to report on ten aspects, including sleep and exercise, on a 5-point scale.

2.4. Medication history and adherence

Keeping an accurate medication history for patients is important because it helps in better planning future treatment, and it is a chance to educate the patients about their medications [30], as well as detecting medication-related problems when patients are not able to report their medications history accurately [31]. However, the effect of medical treatment not only depends on diagnosing the symptoms and picking the suitable medications, but also on patients’ compliance or adherence to these medications [4]. Compliance is defined as the degree to which the patients follow their medication practices [4]. Studies have proved that poor medication adherence

result in significantly less improvement in the patients' condition across different chronic diseases, including PD [32][33].

Generally, patients are not adherent to their medications 50% of the time according to the 2003 World Health organization report on medication adherence [5], and also patients tend to hide their medication taking behavior from their providers and even families for many reasons either intentionally or unintentionally (for example to please the provider or fear of embarrassment), which affects the medications tracking process [6]. Patients also tend to overestimate their adherence by 200% when being interviewed [34], and this method is time-consuming and can have some bias [4].

Normally clinical estimation is used for assessing the patient's adherence, however, most clinicals do not know their own patients' compliance as they believe [35]. Another approach is using a diary or a journal to report the medication intakes regularly, as studies have confirmed that using a diary can be a reliable method for collecting accurate data from the patient [7][8].

The results of a study made on an e-diary suggest that the e-diary is an excellent way to monitor patient reported medication intakes and adherence [7]. An internet smartphone e-diary application tailored for patients of multiple sclerosis was made in [8] and achieved this idea, where patients were asked to mark their actual time of medication intake in the e-diary, by clicking on a reminder notification and then confirming their intake time with another click. However, the app testing found that smartphone reminders notifications did not improve the adherence to these medications, but nevertheless the adherence issue was detected.

Another similar medication journal was implemented in STOP mobile application [24] which intends to log the medication intakes of PwP. The medication journal in STOP allowed the users to record when they took their last medication using time manual input or via voice input, as shown in Figure 2.

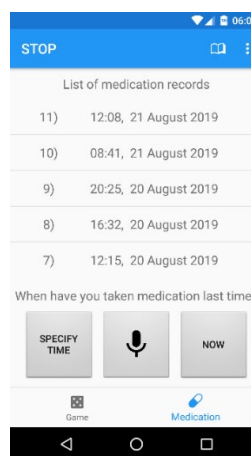


Figure 2. Medication journal interface of STOP app, logging medications time using manual input, voice input, or a “Now” button [25].

2.5. Visualizing collected data

To get the most out of the data collected by the app, it should be presented in a good way. A recommendation by [9] is to emphasize important data by visualizing them with graphs, as interpretation of most data is easiest with good graphs. However, the paper warns that poor graphs can lead to serious misinterpretations just as statistical assessments providing false conclusions. It states that the most important principle when constructing a graph is to express the message that its creator wants to convey in the most efficient way possible, from the scientific and statistical points of view. Therefore, a general rule by the authors is that all graph elements need to be helpful, not distracting, and emphasizing important data [9].

The data in the app cover many aspects for PwP, the app collected game scores, medications intakes, and daily symptoms surveys. Each part of data would need its own graphical representation, so that we have separate independent visualizations that we can make conclusion from.

Hence, there is a need for a platform to present these graphs in a useful and organized way. A good platform to put these graphs together is by using a dashboard. According to the big book of dashboards [10], a dashboard is a visual display of data that can be used to monitor some conditions or help understand the data. The dashboard should be designed for the purpose of demonstrating important data in a relevant way to the end users. Although the big book of dashboards suggests that there is no such thing as a perfect dashboard, the book tries to give some rules for a good a dashboard. The book recommends using charts rather than tables wherever possible because they are better for our visual system to spot trends and relationships, the book also shows some examples where using suitable sizes and colors for the target users is important, for example to emphasize important data or for keeping the interface understandable.

One easy way mentioned by the book is using a bar chart which is widely used as it is the most effective way to compare different categories, these bars can be oriented horizontally or vertically, and they can be sorted out to infer a relationship when needed. Another suitable way for simpler charts is using a scatter or dot plot, which even needs smaller space and lets us compare values across two dimensions.

3. DESIGN WITH PARKINSON'S DISEASE IN MIND

The motor symptoms of PD, especially the tremors, affect many of the patients' daily activities, including their interaction with smartphones. Therefore, normal mobile apps made for healthy users would probably have issues with PD patients, and so, when creating a new app for PD patients, some adjustments should be made. However, studying symptoms alone might not be enough to make the best design choices for the mobile app, and understanding the problems that PD patients have when interacting with their smartphones is a necessity. A comprehensive study was made for this exact purpose in 2015 [36], the objective of the paper was to study how PD affects the patients' interaction with their smartphones' touchscreens, in order to find more suitable interfaces for PwP.

The authors of the paper conducted a study of 3 phases, the first phase was a literature review of PD to better identify possible smartphone interaction issues. In the second phase the authors conducted 8 interviews with health professionals with long training and experience working with PwP, among important findings were that rigidity makes interaction sometimes slower and less accurate as it is harder to move the muscles. Health professionals reported a condition called "dyskinesias" which PwP develop when they have too much medications in their bodies, dyskinesias was described by an interviewee as the involuntary arms movement that a healthy person (without PD) encounter when using a mobile phone on a moving bus. This condition can make interaction with smartphones even harder for PwP if they are using their phones when having this condition. Another notice by the interviewed health professionals was that PwP usually experience short-term memory loss as part of the disease in addition to being age-related, this could reflect in forgetting new medications for example or the need to be reminded about tasks or instructions when using a new app.

But most importantly was the third phase, which consisted of usability experiments with 39 PwP (average age was 64), to identify the elements that cause interaction issues with the smartphone, four tests were completed by the participants, they were mainly testing the (a) tap; (b) swipe; (c) multiple-tap; (d) drag.

The accuracy of the tapping test was calculated based on the number of the precise taps to the target. The tap experiment has showed that the size of the target had an impact on the accuracy, where the best accuracy was achieved in square targets with side length of 14 mm or more.

The accuracy of the swiping test was calculated based on the reaction time, number of touches needed per swipe and the speed of swiping. The swiping test has showed that PwP are able to perform swipes with good accuracy. The accuracy of the multiple-taps test was calculated based on the time needed to perform a number of ten successive taps. The multiple-taps test shows that PwP could perform successive taps with good speed.

The accuracy of the dragging test was calculated based on the time needed to reach a desired spot. The test shows that participants were a little slow to reach their goal, but reaching the goal without further adaptations.

The paper established 12 user interface guidelines based on these findings that can help design more suitable smartphones apps for PwP. Among these useful guidelines were advices to using square tapping targets with 14 mm side length, using swipe gestures when needed but without activation speed, using drag gestures as least as possible, using high contrast elements to overcome the visual problems some PwP have, carefully selecting the information to display to overcome the some-term memory loss PD symptom, as well as informing users clearly about their current location in the app, avoiding time-dependent controls as they can be challenging for PwP, and lastly considering smartphone guidelines for the elderly when designing for PD as PwP are diagnosed after the age of 50 in 96 % of the cases.

Based on the 12 user interface guidelines that the paper concluded, the app was designed with these considerations in mind: the use of big buttons where these buttons are either square or rectangular shaped buttons, making the interaction mostly using taps, allowing most screens to take 1 full page only to minimize swiping or scrolling, minimizing the number of clicks by choosing suitable default options, providing clear instructions on the home page to help users when needed (in addition to the one-time explanation by the doctor to every patient at the beginning). Also, big fonts for the elderly are used, as most screens do not have constant font size, but rather relative to the screen size, making it suitable for different smartphones and tablets when used. Figure 3 shows the home page of the app reflecting these conclusions, and other parts of the app will be discussed later in chapter 5.

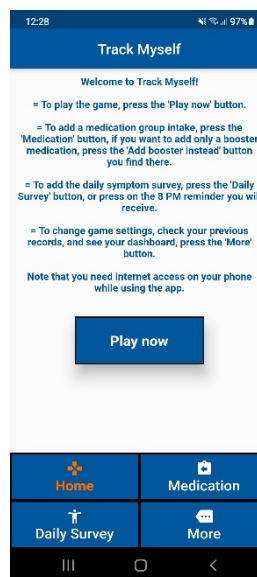


Figure 3. Home page of Track Myself app, having app instructions, big rectangular buttons, big fonts, with no swiping needed, but rather minimal number of taps.

4. TECHNOLOGY AND SOFTWARE

4.1. Adobe XD

Adobe XD is a powerful tool that helps in designing prototypes that look and feel like the actual to-be-developed product, so this design can be shared and edited by different team members efficiently before implementing this product [37]. The product can be a website, a mobile application, or a game. It is available on Mac and Windows to fit cross-platform teams, and designs can be shared through customizable share links. It has components that fit different projects, like buttons and text fields, where there are many supported user interfaces (UI) kits like the Android UI kit. It supports also wireframing between different screens to imitate the actual user flows of the app, for example navigating to another screen when pressing some button. This helps designers understand how the product will look and behave on an actual device. All of that is done prior to coding or implementing anything.

“Track Myself” app was initially designed and wireframed in adobe XD, where suggestions and comments were added by the thesis supervisors. Shown in Figure 4 are some screenshots of the screens designed. Design can be viewed from: <https://xd.adobe.com/view/8d4ca465-2983-4aa6-95d4-8b535fe6906f-d81f/>

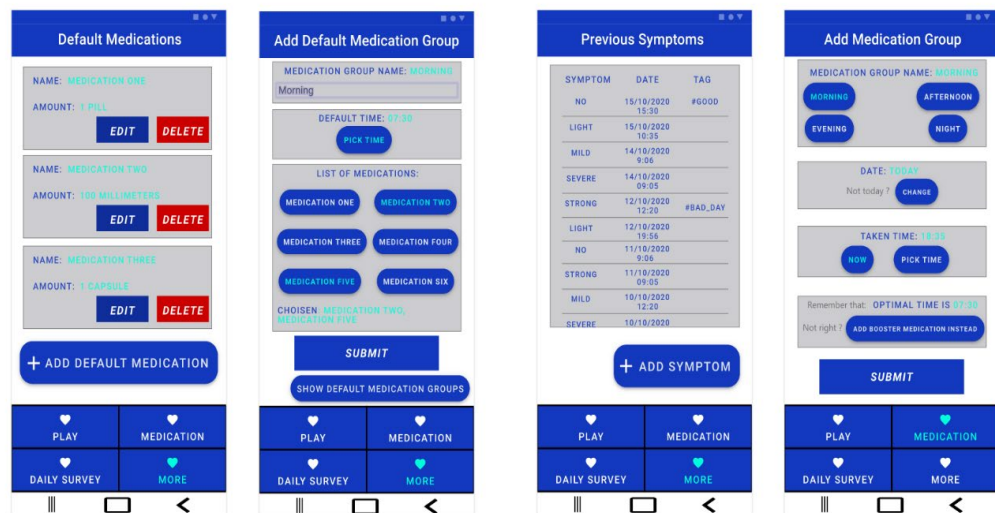


Figure 4. Screenshot of some of the designed screen interfaces.

4.2. Flutter

Flutter is Google's UI toolkit for building good-looking, natively compiled applications for mobile, web, and desktop from a single codebase [38]. Flutter uses Dart programming language. Everything in Flutter UI is a widget that has a configuration and a state which allows for full customization. Flutter provides native performance for both Android and iOS using the same codebase, meaning that the code is written only once and can run on both platforms. Also, Flutter has built-in widgets that look uniquely on Android and iOS, they are the Material design and Cupertino widgets, respectively, to offer the best platform flavor look.

"Track Myself" mobile app is made using Flutter and Dart and is limited to Android only for now, because iOS needs a paid developer's license and iOS devices for testing. The code editor used was "Visual Studio Code", and an Android device emulator was used to show progress along with physical Android devices.

The minimum Software Development Kit (SDK) used in the app is application programming interface (API) level 22, Android 5.1 Lollipop, and will run on approximately 92.3% of devices according to Android studio. The source code for the app is available at: <https://github.com/FadyTawfeek/track-myself-flutter-app/>

4.3. Firebase

Firebase is a service made by Google to work as a backend for most products and apps [39]. It is easier than most traditional backend servers as it needs little to no management by developers, and there is no need to APIs from scratch. It works well with mobile app development, and it has features like real time databases, authentication, and cloud storage.

"Track Myself" app is using Firebase to store the users' data; the app uses real time database feature that Firebase offers to store and sync the users' data in real time. Data collected by the users like game scores, medication intakes and so on, are stored in Firebase in JavaScript Object Notation (JSON) format. They are stored according to the unique device ID that each user has, which is detected automatically by the app making it easier for the users as they do not have to create an account or sign in to the app at any time. A sample of how the data looks like on Firebase is shown in Figure 5.

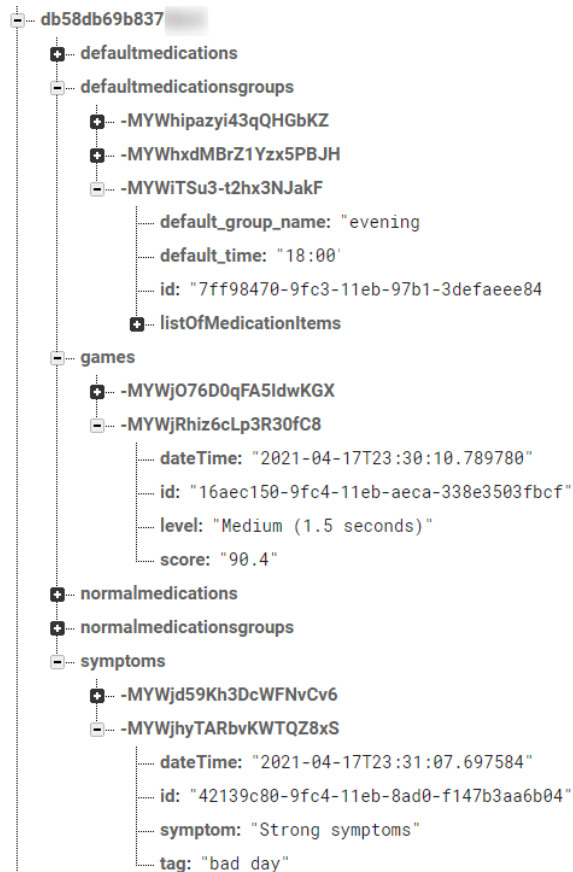


Figure 5. Screenshot from Firebase showing data for some device ID.

4.4. R Shiny

Written in R programming language, Shiny is an R package that help build interactive web apps [40]. It allows hosting standalone apps on a webpage and building dashboards. Shiny apps can be extended with HTML widgets, CSS themes, and JavaScript actions. Shiny apps can be put on the web using developer's own servers or using RStudio hosting service.

“Track Myself” app has a dashboard made with R Shiny, it has small amount of HTML use, it uses the device ID of the user to access their data, and it is deployed on R studio's hosting service, on the link: <https://fadytawfeek.shinyapps.io/Track-Myself/>

4.5. Google Drive and Google Forms

Google Drive is a safe environment to store and share files and folders on different platforms [41]. Services built-in Google Drive include Google Docs, sheets, slides, etc. Google Forms is a tool that creates surveys, polls, etc., it supports different question options like multiple choice, dropdowns, linear scale, etc. [42]. The surveys even support many styling options, and responses are automatically analyzed with real time charts.

“Track Myself” app used Google Drive to store the Android Package (APK) file to be sent to the testing participants, so that they can download and install it easily on their phones. Also, info about PD and instructions for the testing tasks were given to the participants using Google Docs within the same Google Drive folder. The app also used Google Forms to create the questionnaire for the testing participants after they tried the app.

5. IMPLEMENTATION

Track Myself app was developed to help PwP solve the issues discussed in section 2 while being easy to understand and use by following the stated design guidelines. The app consists of 5 main features: The game, the daily symptoms survey, the medications journal, previous records section, and the dashboard. To assess the severity of the PD symptoms for the patients, the game together with the daily symptoms survey are being used. To collect medication history and measure the medication time-adherence of the patients, the medication journal is being used. To visualize the data collected and make conclusions from these data, the dashboard is being used.

5.1. The game

As mentioned in Subsection 2.2. utilizing some game features can be used to assess PD symptoms level and substitute the clinical methods to some level. While using a game to assess PD symptoms may not be as accurate as the clinical methods, it has the advantage of being more frequent unlike the traditional clinical review that happens every 6 months [1]. Therefore, a game was implemented in the app to take advantage of this.

The idea of the developed game depends on using the accelerometer sensor of the smartphone to measure the hand tremor severity as this smartphone sensor can be used to quantify the tremor of PD [21][22][23], which is one of the most common symptoms of PD [12][20]. This game could be an improvement over the STOP application game as it uses the accelerometer data in calculating the score instead of the ball deviation distance from the center in relation to the whole screen [24].

The Track Myself game is made of a ball which changes its location depending on the accelerometer readings that reflect the player's hand movement. The player is instructed to keep the ball in the center of a small green circle for a pre-set time, the timer of the game starts when the ball is successfully put in the green circle. The ball and the small green circle are the same size, meaning that the player should be accurate to start the game timer. The timer is reset, and the ball becomes red when the ball gets out of the green circle.

The game has three possible difficulty settings that the player can choose from the settings menu: easy (0.5 seconds), medium (1.5 seconds), and hard (3 seconds). Considering the needed precision to start the timer, these relatively short times were chosen. The game also has a maximum time of 30 seconds, where the player gets a score of zero if when the time is up.

As shown in Figure 6, the player is given quick instructions about the game and given a tip to start the game while holding the phone horizontally for a better score. The player then presses “Start” to play the game, and after the game ends, they have the option to submit the score or try again. The user is given different feedback depending on the score, in order to increase the users’ motivation to play the game more often.

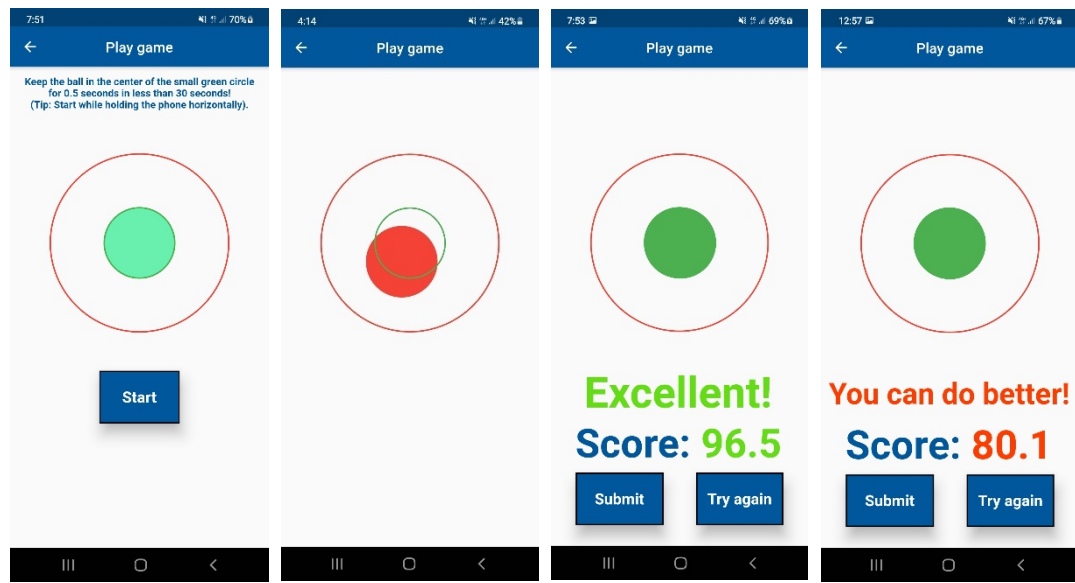


Figure 6. Screenshots of the game interface of Track Myself app, first from the left: before the game starts, second: during the game, third and fourth: reporting the score.

How the score is calculated:

The accelerometer sensor measures the device movement in the three dimensions. The game extracts only the X and Y dimensions needed, then these two readings determine the position of the ball during the game. The bigger the accelerometer reading is, the greater the distance of the ball from the center. The accelerometer event is calibrated to read zero when the ball is exactly in the green circle and read values between -10 and 10 in each dimension. For example, in Figure 7, the accelerometer reads a value of 0 in X and -10 in Y, therefore, the ball reached the bottom point which happens when the user is holding the phone in a straight vertical position ahead instead of the correct horizontal position.

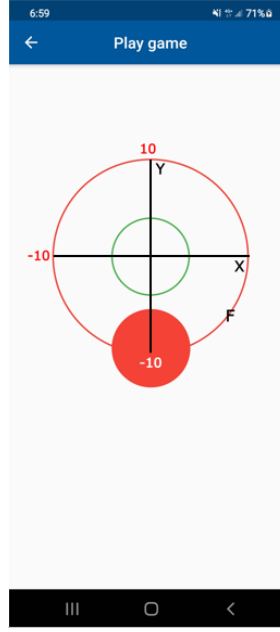


Figure 7. How the ball moves according to the accelerometer readings.

This ball position is just an indicator for the user to adjust their phone, but the accelerometer readings will be used directly in the score calculation. The score of each accelerometer snapshot is then calculated by taking the average of the **absolute** accelerometer readings in X and Y dimensions, so the worst case is when the user has the ball in one of the four corners (for example at point F in Figure 7), which indicates the highest possible tremor level. The accelerometer sampling rate is set to 100 Hz (100 samples per second) which should be suitable for the needed accuracy level of the game. Then the final score is the average of all the snapshots captured until the user finishes the game, as shown in Equation (1),

$$Score = 100 - 10 \sum_{i=1}^n \frac{(|x| + |y|)/2}{n} \quad (1)$$

where x is the absolute X-axis accelerometer event (0-10), y is the absolute Y-axis accelerometer event (0-10), i is the counter of the snapshots, and n is the number of accelerometer snapshots captured until the game ends (every 10ms).

The game is finished in two cases; (1): when the accelerometer reads minimal readings allowing the ball to be in the center of the screen for the time set in the game (0.5 - 3 seconds), where the ball itself turns to green color; (2): when 30 seconds have passed without achieving this target, giving a score of zero. Figure 8 shows a part of the code used to calculate the score in case of a successful game.

```

// when the game starts:
timer = Timer.periodic(Duration(milliseconds: 10), (_) {
  counter += 1;
  totalAccelerometer +=
    ((event?.x?.abs() ?? 0) + (event?.y?.abs() ?? 0) / 2);
});

// when the user reaches the game target time:
score = totalAccelerometer / counter;
finalScore = 100 - (score * 10);

```

Figure 8. Part of the code used in the score calculation.

5.2. Symptoms survey

As mentioned earlier in Subsection 2.3. self-report symptom assessment method has proved to be an important indication for PD severity, and can complement the existing clinical assessing practices. So, in this app I implemented a daily symptoms survey as a second factor (in addition to the game) to assess the symptoms level of PwP. The survey should be filled daily by the patient. The patient chooses the severity level of the PD symptoms they have every day from 5 possible options, starting from light to severe symptoms, as shown in Figure 9. The patient can add an optional comment of maximum 20 characters, that the patient can use to describe their symptoms, feelings, or events in words. To minimize the number of touches required by the user, the date of the survey is set to today's date by default, which represents the best case when the patient is filling the survey on the same day. The patient has the option to edit the date as well (for example in case they report yesterday's symptoms).

The daily symptoms survey is accessed by the user by two methods, the first method is directly from the app from 'Daily survey' button, and the second method is by clicking on the reminder that is sent to the user. The reminder shown in Figure 9 is sent to the user every day at 8 PM, which should be a suitable time for the user to evaluate his symptoms level for the day, as indicated by some user feedback in STOP app [24] that reporting symptoms on the same day is better than the next morning.

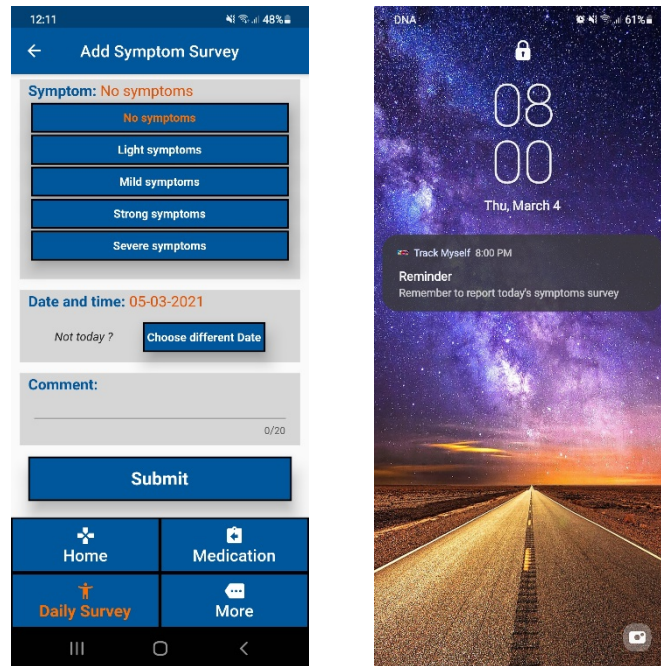


Figure 9. Left: screenshot of the daily symptoms survey in Track Myself app. Right: screenshot of the symptoms survey reminder sent daily to users at 8 PM.

5.3. Medication journal

Keeping an accurate medication history for PwP is an important step in calculating their medication adherence and improving their treatment plan as discussed in Subsection 2.4. An e-diary can be a good solution, as it keeps track of medication history for the patient with minimal bias in self-reporting if the process is accurate, and this medication history can be used later to calculate the adherence to these medications. Therefore, developing a medication journal is an essential part of this new app.

The medication journal is divided into two parts, the first part is made for the doctors to decide on the default medications that each patient should take, and the second part is made for the patients to log their intake for these medications.

Because PwP usually take multiple medications together in certain times every day, the medication journal uses the idea of “medication groups”. A medication group is a collection of medications that the patient regularly takes at a certain time of each day. A medication group can also contain a single medication for that time of the day if that is the case.

At first, the doctor creates all the default medications that the patient should take in the upcoming treatment period, where the doctor also chooses the dose of each

medication item. Next, the doctor forms some medication groups out of the medication items he added previously, where each medication group has an optimal time when the patient should take this medication group, as shown in Figure 10.

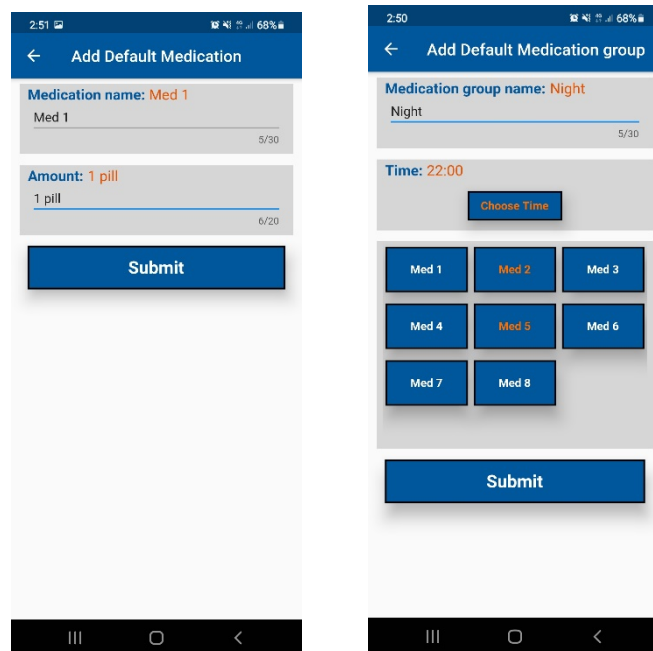


Figure 10. Screenshots of doctor's screens to create default medications (left) and default medication groups for the patient (right).

The previous steps are done by the doctor only one time before the patient starts using the app, then later on, the doctor has the option to add/delete medications and medication groups based on his insights of the patient's needs for the upcoming treatment period. After the doctor adds the medications, they also give instructions for the patient on using the app so that they take full advantage of it.

The patient uses the medication journal to log their two possible types of medications, the first type is the medication groups that are prescribed by the doctor, and the second type is the so-called "Booster medication". A booster medication is the type of medication that the doctor advises the patient to take only when highly needed (for example in case of a symptoms rush), a booster can be any of the default medications that the doctor entered earlier for the patient.

As shown in Figure 11, the medication group intake page asks the patient to select the group name that they recently took. To minimize the number of touches required by the user, the time is set to now's time by default, which represents the best case when the patient is logging the group just after they took it. The patient has the option to edit the time as well (for example in case they took it on time but forgot to log it).

As mentioned earlier, each medication group has an optimal time agreed on by both the patient and the doctor, so, when the patient is logging a medication group, they are reminded about the optimal time for this group and asked if they are willing to log a booster medication instead, which directs the patient to the booster medication logging page. The booster medication intake page asks the patient to select the booster's name and the dose they had to take of it, and as earlier, the time is set to now's time by default, but the patient has the option to edit the time as well.

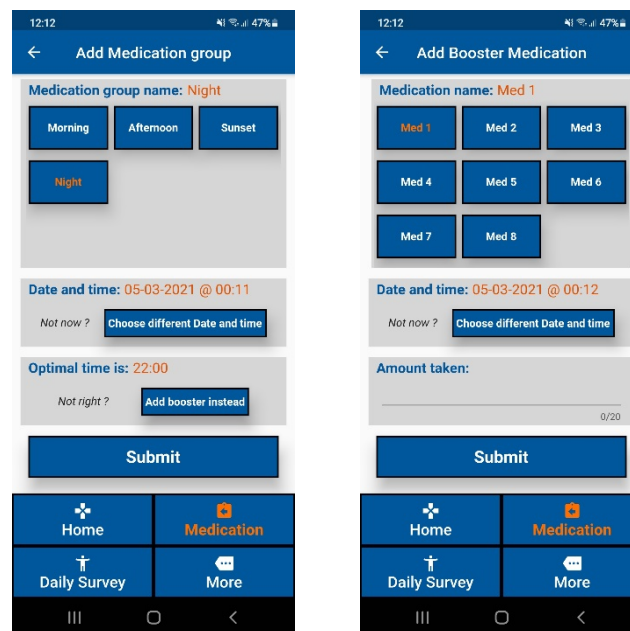


Figure 11. Screenshots of medication journal inputs to log medication groups (left), and boosters (right).

Logging the medication groups and booster medications aims at keeping track of the medication history of the patient as well as assessing their adherence. This can help doctors evaluate the efficiency of these medications in treating this specific patient, by making comparisons with game scores, daily symptoms surveys over time, which we will discuss later on in the dashboard part.

This medication journal was made specifically for PwP, however, it can also benefit normal patients taking significant amounts of regular medications that need monitoring and adherence evaluation.

5.4. Previous records

The app also has the option to view the user's previous logs for game scores, daily symptoms survey, medication groups, and booster medications. These four previous records screens can be accessed from 'More' menu and then the wanted log [Figure 12]. Showing the previous game scores to the user can motivate them to play the game more often, and even try to improve their score [Figure 12]. The scores are shown in different colors, starting from green to dark red, while also acknowledging the game level each score was played in, for more user engagement. The previous symptoms surveys are also showed in different colors depending on the reported symptoms level, starting from green to dark red [Figure 12]. Showing the medication groups and booster medications records [Figure 13] will remind the users about their recent medication intakes, for example to make sure they took some certain medication group or not, which could be a needed feature considering the extra short-time memory loss that some PwP have [36]. The user also has the option to delete a certain log element (for example if they have added it by mistake), and the app asks for a confirmation before deleting, and then show a bottom notification dialog stating either 'Record deleted!' or 'Deleting failed!'.

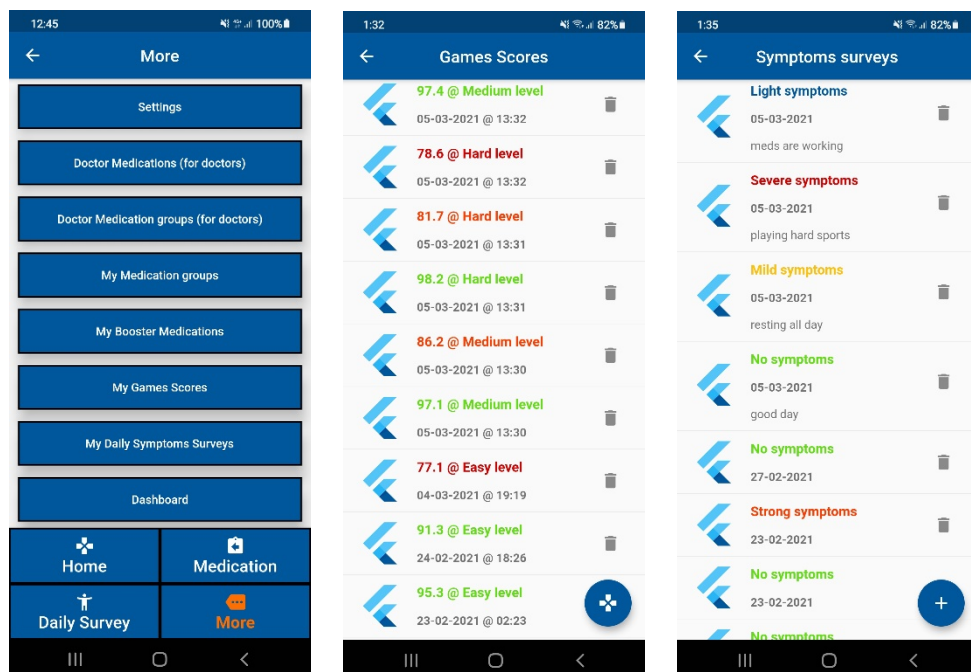


Figure 12. Screenshots of “More” tab (left), and previous records of game scores (middle), and symptoms surveys (right).

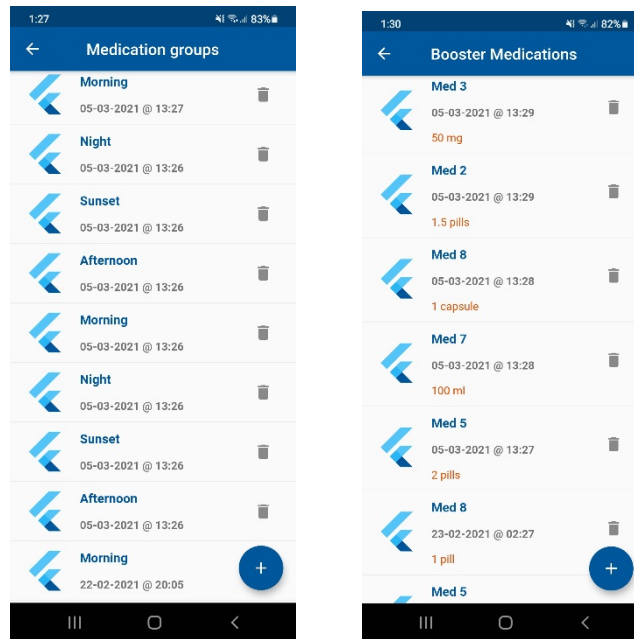


Figure 13. Screenshots of previous records of medication groups (left), and booster intakes (right).

5.5. Dashboard

The dashboard complements the app and was partially developed by me prior to the thesis work. Further development and modifications were made to the dashboard to fit the app.

The dashboard is an important part of the app. As mentioned earlier in Subsection 2.1. PD progresses differently in each individual and customized treatment plan for each individual are in need. Now that we collected a good amount of data about the patient's symptoms level and for their medications' intake history, we need to form relations between these logs that present the full picture and suggest better future treatment ideas. This is done by visualizing the records with respect to time, so that doctors and clinicals can detect changes in the patient's symptoms level, whether improvements or worsening, and plan better future treatment based on these changes.

The dashboard is intended to be used by the doctors, and the dashboard is hosted on a webpage so doctors can access the patient's data using their device ID. Device ID is a 64-bit number (as a hexadecimal string), which is unique identification for each mobile device. However, the dashboard can also be accessed by the patients directly from the app or using a normal browser. The app provides the device ID for the viewer and instructs them how to reach their data on the dashboard as shown in Figure 14.

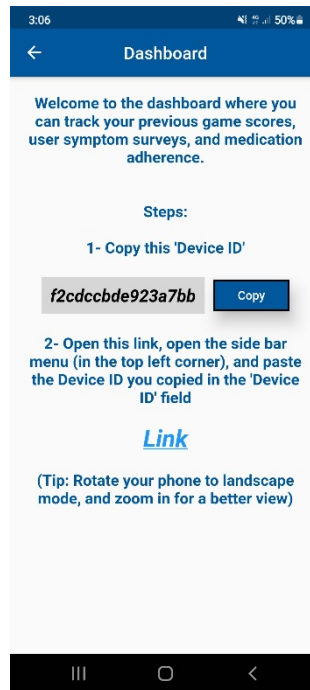


Figure 14. Screenshot of the dashboard access and instructions page.

There are three visualization charts in the app, each chart presents a part of the data collected on the Y-axis against their dates on the X-axis. The dashboard user chooses the desired date range for the data where these dates are shown on the X-axis. Info about what each chart represents, what the lines in the charts indicate, and instructions for a more detailed view are provided to the dashboard user before they enter the device ID, as shown in Figure 15. Also, the dashboard indicates errors in case a wrong device ID is entered, or if the selected date range does not have data for the patient.

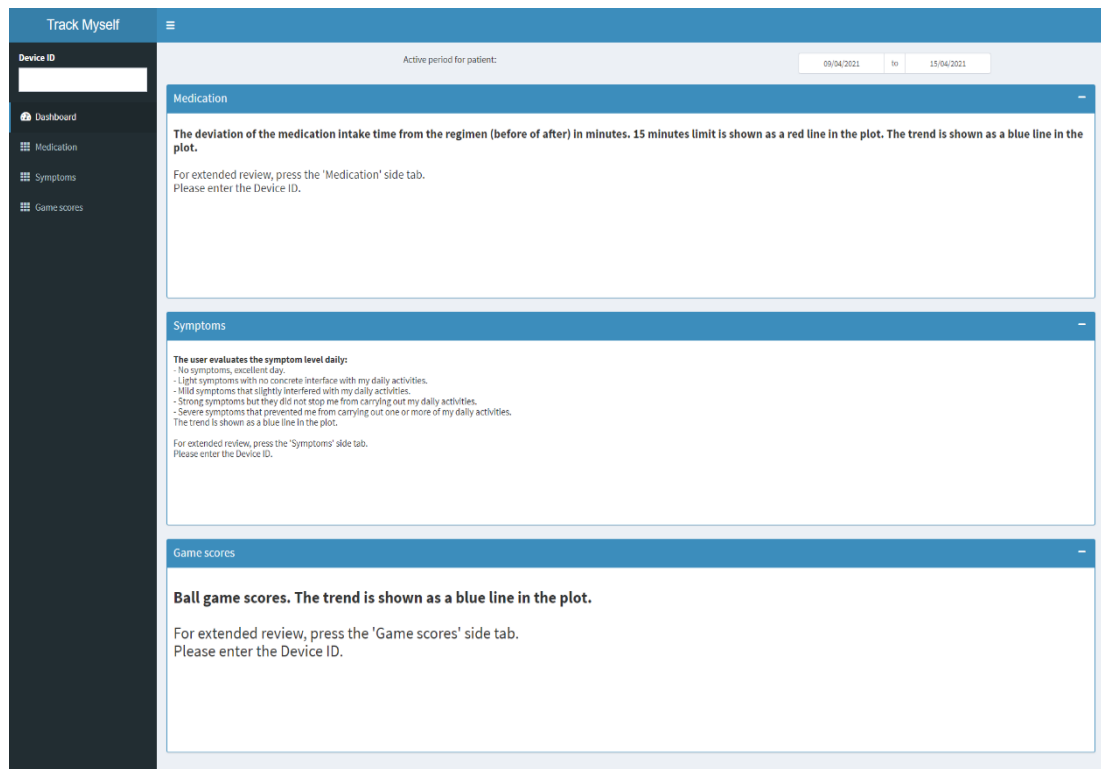


Figure 15. Screenshot of the dashboard before entering the device ID, with information about each chart.

The first chart represents the medication adherence of the patient, where only the time-adherence is shown, not the missing or wrong doses. This is done by calculating the difference in minutes between the intake time of the medication groups and their optimal times, for example, if the patient has a medication group called “Morning” that they should take at 10 AM, and then the patient takes it at 10:20, then the difference is 20 minutes, and so on. The chart represents the medication adherence over time, where the difference in time is shown on the Y-axis in mins. There is also a horizontal red line shown indicating the 15-minute point, which should serve as a break point between punctuate and poor medication adherence.

The second chart shows the symptoms survey results on the Y-axis. The third chart shows the game scores on the Y-axis. There is also a blue line present in all the charts, representing the trendline of all the scores in these charts. This trendline shows the direction of the scores, and it is calculated based on all the logs entered by the user for his usage of the app, even when choosing a smaller date range, which should give an indication of whether the results and logs are getting better or worse, for example if the trendline of the game scores chart has a positive slope, this means the game scores are improving.

Active time for patient is shown also on the top of the page indicating the date range the patient has used the app, which can remind the doctor about when each patient was active so that they show relevant rate range for this particular patient.

The active time for each patient is determined by the first and last day the patient has played the game in the app. The logs are viewed accurately in time, that each element is viewed according to time of the day, for example the “Morning” group intake is viewed before (on the left of) the “Afternoon” group intake, despite being in the same day. Figure 16 shows a screenshot of the dashboard after the user enters the device ID, and the date range selected is 7 days.

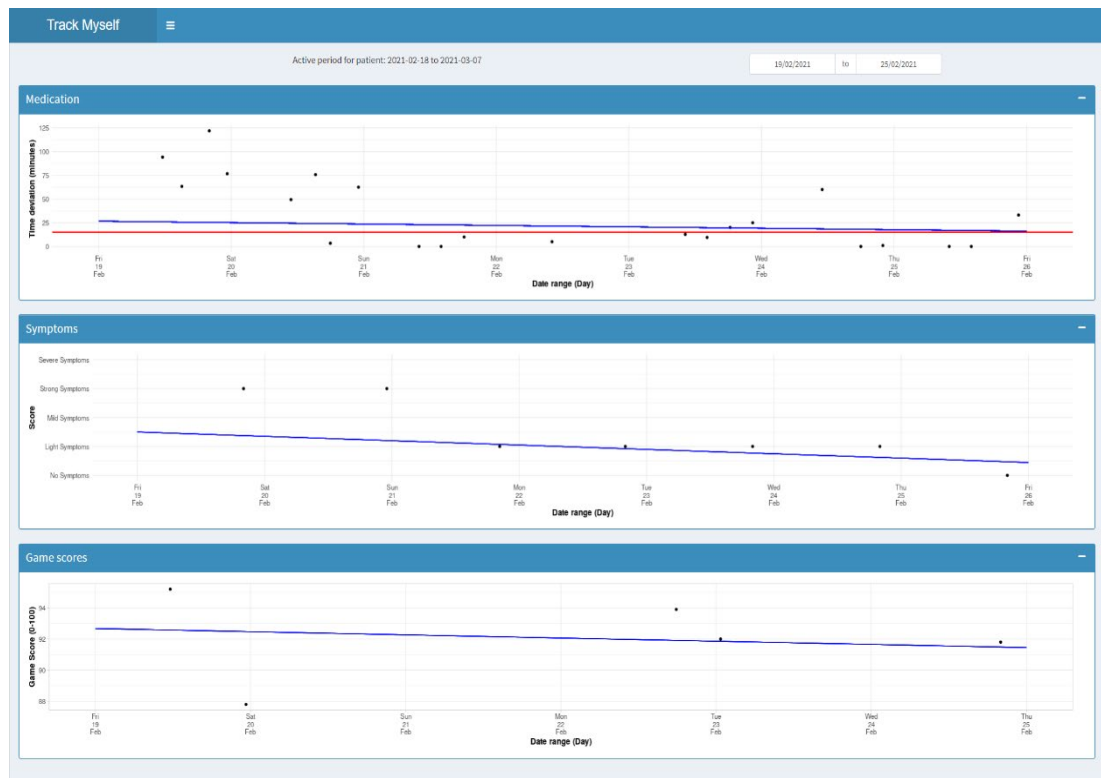


Figure 16. Screenshot of the dashboard with data viewed after entering a device ID.

When opening the dashboard, the date range is set by default to be the last 7 days, until the user changes the date range. The date format on the X-axis depends on the date range chosen as shown in Table 1. For example, Figure 17 shows the dashboard when the date range selected is a few weeks, and Figure 18 shows the dashboard (with same data as Figure 17) when the date range selected is a more than a month.

Table 1. Different date formats in the dashboard depending on the chosen date range

Date range selected	Date format	Example
1-7 days	Day Day number Abbreviated month	Fri 09 Apr
8-28 days	Week number	15
29-365	Abbreviated month	Apr
366 or more	Year	2021

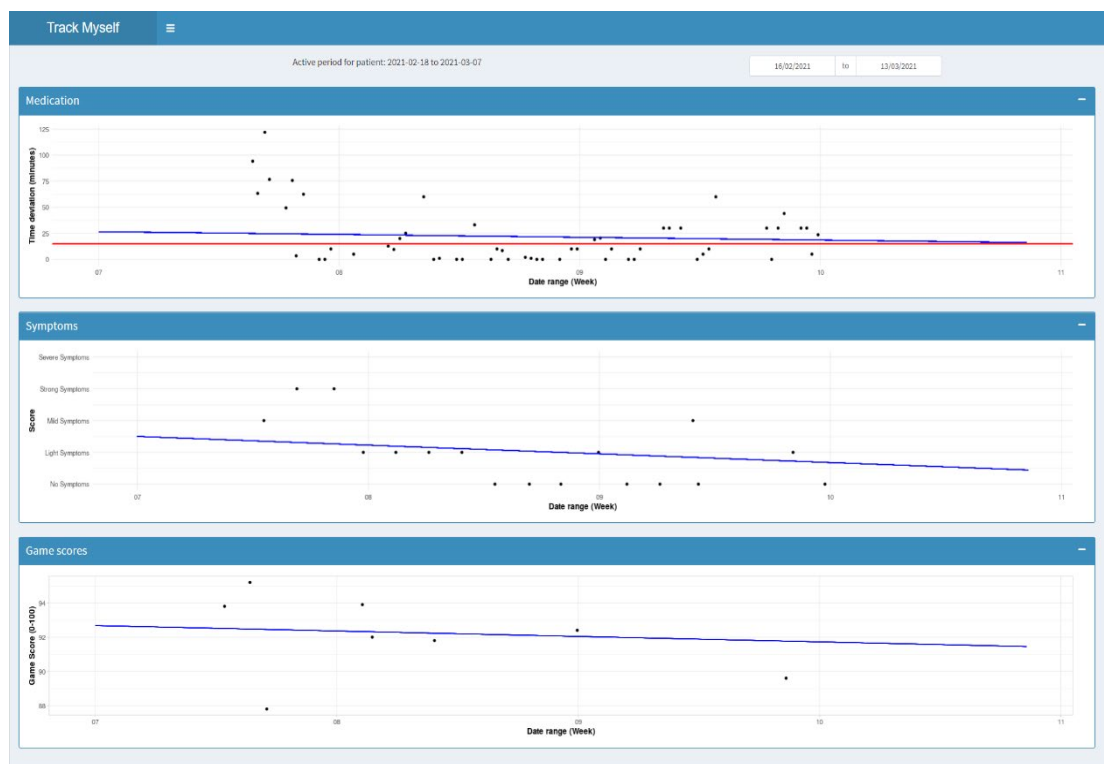


Figure 17. The dashboard where the date range selected is a few weeks.

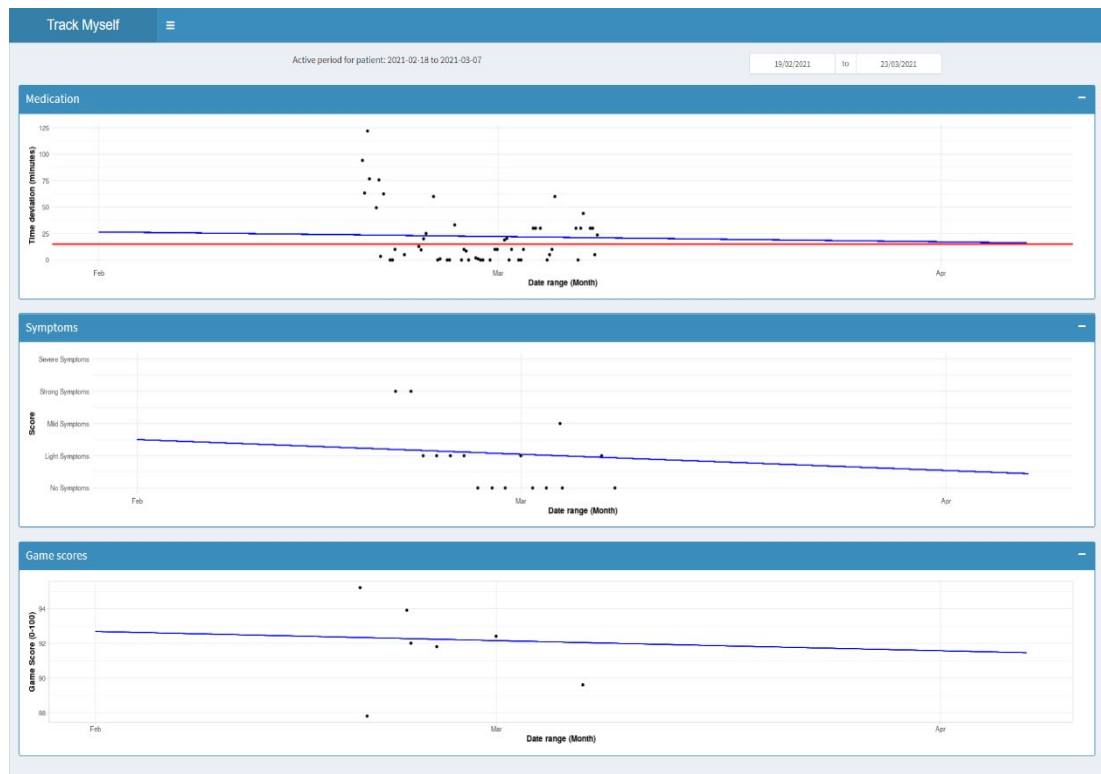


Figure 18. The dashboard where the date range selected is a more than a month.

The dashboard also has three side tabs that display each of the three charts separately on the whole screen, with the difference of always having a date format of “Day, Day number, Abbreviated month”, for example “Fri 09 Apr”, even for longer date ranges, which should give a more detailed view of each chart. The dashboard detects the date ranges and changes the orientation of the date text, to fit well on the screen for longer date ranges. For example, Figure 19 shows the dashboard when a long date range is selected for the medication adherence side tab, and Figure 20 shows the dashboard when a long date range is selected for the symptom surveys side tab.

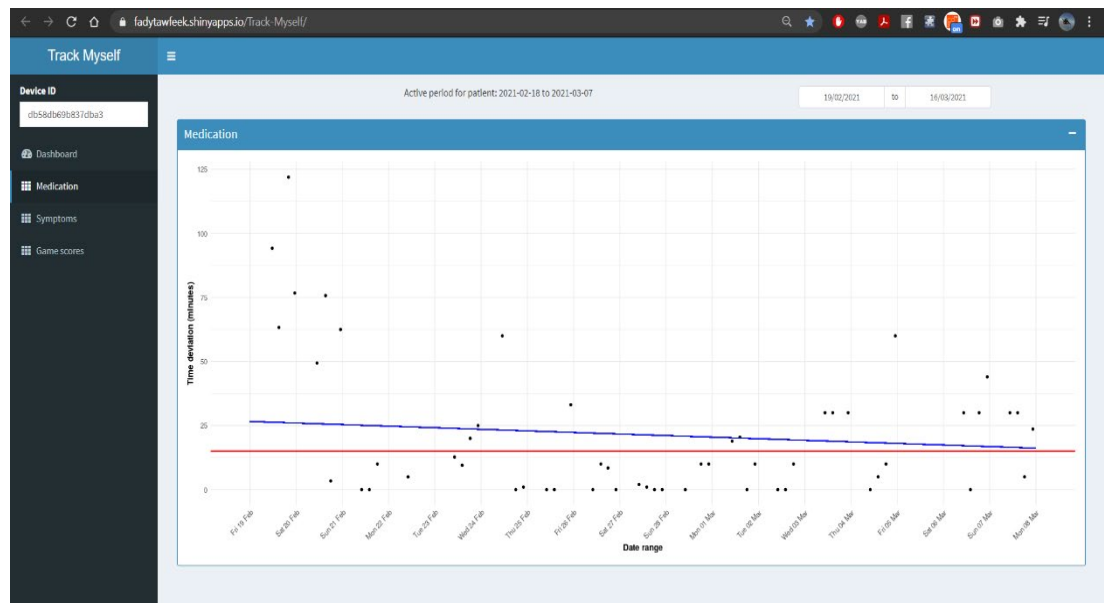


Figure 19. Medication adherence side tab with long date range selected.

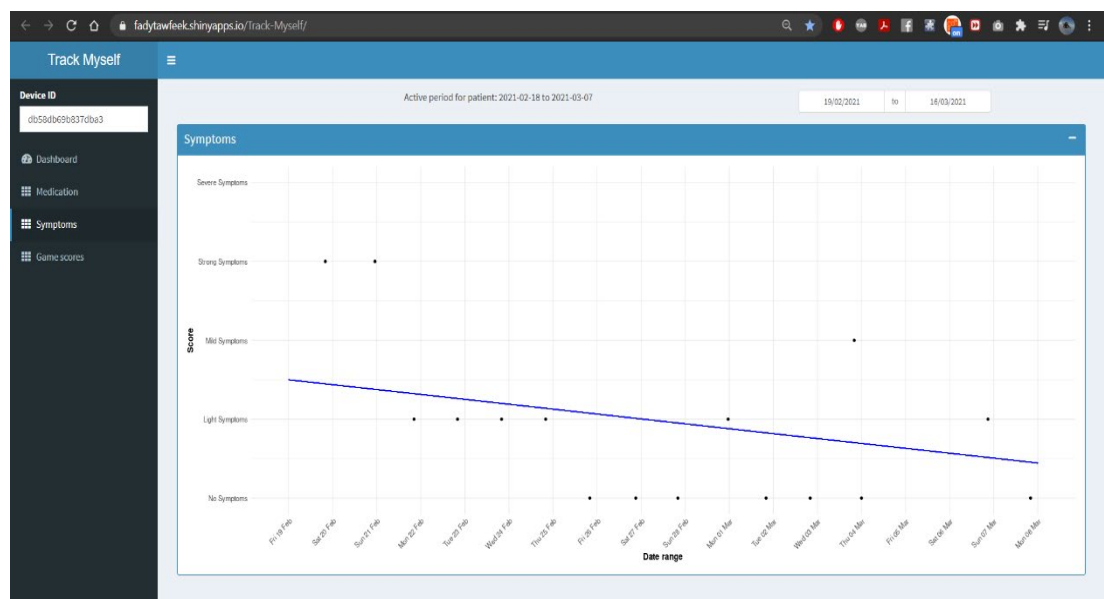


Figure 20. Symptoms surveys side tab with long date range selected.

The dashboard is designed to benefit both the patients and doctors, as it visualizes all the patient's logs in an understandable way, where the doctor can deduce relations between different charts, for example detect if having a more punctual medication adherence makes a difference in the symptom surveys filled by the patient or the game scores.

6. EVALUATION

Evaluating the application is an important phase in the development process, to improve the app and discover possible future plans. It is also important to test the usability as well as other technical aspects of the app, especially because of the hard target group the app has.

6.1. Testing

The app has 2 target users, the doctor and the patient, the testing focused only on the patient side of the app as it is the crucial part that need to be as easy as possible. The prescription of the medications was loaded automatically for the users in this testing version (the doctor's first role), so that they all have the same default medications. The doctor's menus were deactivated to prevent the participants from accessing them and editing any of the loaded medications and medication groups, as shown in Figure 21.

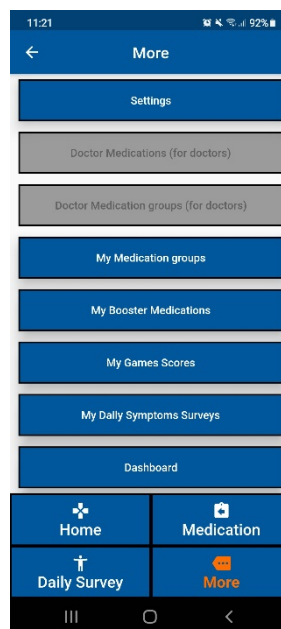


Figure 21. Screenshot of “More” menu with disabled access to doctor’s menus.

The app was tested for 2 weeks by ten volunteers aged between 16 and 47 years old, they were 5 males and 5 females. They are healthy users with no symptoms of

PD, which is a convenient sample due to the ongoing COVID-19 pandemic. So, the healthy users were asked to act in a persona of a patient suffering from PD while using the app and while filling the questionnaire later, 2 personas were described for the participants and they were asked to act as one of them. They were also given information about PD and about the app, and tasks to be done in these 2 weeks to be able to answer the questionnaire. The document sent to the participants including this information can be viewed in Appendix 1.

The tasks involved playing the game few times per day, filling the daily symptoms survey, logging a list of medication groups and boosters few times every day, checking previous records, and intensively trying the dashboard on the last day of the testing.

A usability questionnaire is the most commonly used practice for mobile apps for its simplicity in execution and data analysis [43]. The usability questionnaire I used is a combination of 2 smaller components. The final questionnaire can be viewed in Appendix 2.

The first component is a modern and validated usability questionnaire specifically made for mobile health apps in 2019, it is the mHealth App Usability Questionnaire (MAUQ) for Interactive mHealth Apps Used by Patients, that proved to be consistent and reliable and help compare different apps by comparing how well they score against this questionnaire [43]. The questionnaire tests 3 aspects of mobile health apps: ease of use and satisfaction, system information arrangement, and usefulness. Each aspect has 6-8 rating statements (21 statements in total), where the participants give a rating ranging from 1 (strongly disagree) to 7 (strongly agree). Ease of use and satisfaction statements rate the easiness and learning rate of the app, how good the app interface was, the organization level, and whether they felt comfortable using the app in social settings with the suitable amount of time for them. System information arrangement statements rate the easiness of recovery when making a mistake, how accurate was the navigation between screens, and how entering and viewing information was handled by the app. Usefulness statements rate the how useful the app was in general for their health condition and if their data will reach their health care provider and benefit them.

The second component is made of my own set of questions that cover the unique features and arguments of the app for more specific evaluation, it is made of 14 rating statements ranging from 1 (strongly disagree) to 7 (strongly agree) categorized in the same 3 aspects as MAUQ, along with 5 open-ended questions to get more expressive feedback from the users and some personal information questions. Answers to the open-ended questions can be viewed in Appendix 3. Statements rate how easy it was to understand and use each screen interface in the app (to detect if some specific screen interface had a problem), if the buttons and font sizes were big enough, if the loading time was short, whether they received all the reminders, and how useful each of the app's 5 features was. Open ended questions inquire about how the participants imagine the life of PwP, what usability and technical problems they faced, and suggestions they have for the app.

6.2. Results

Average of the rating questions in the questionnaire first component (MAUQ) was calculated in each of the 3 aspects, and answers from the five open-ended questions were analyzed to provide feedback and future improvement ideas for the app. Also, features of the app were rated separately by the participants for more specific judgements. The data that the participants entered in the app was sufficient for their testing period, however, there was no need to analyze the data itself as they are collected from non-PD patients, for example it was noted that game scores were mostly high, which does not imply a lot, but infer that the game level should be suitable for PwP.

6.2.1. MAUQ Results

The participants rated the app as satisfying and easy to use, scoring a mean of 6.04/7 in MAUQ. Figure 22 represents the ratings of the 10 participants for each MAUQ statement (MAUQ statements 1-8).

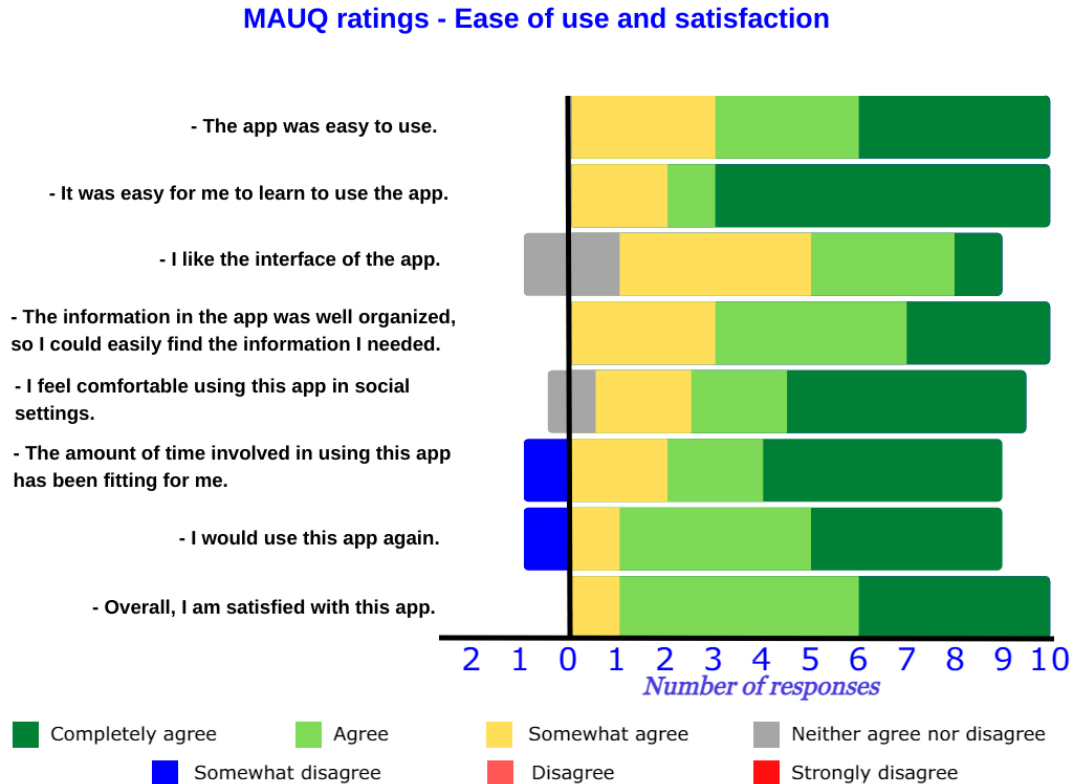


Figure 22. Ratings for the MAUQ ease of use and satisfaction statements.

The participants rated the app system as well managed, scoring a mean of 6.33/7 in MAUQ. Figure 23 represents the ratings of the 10 participants for each MAUQ statement (MAUQ statements 9-14).

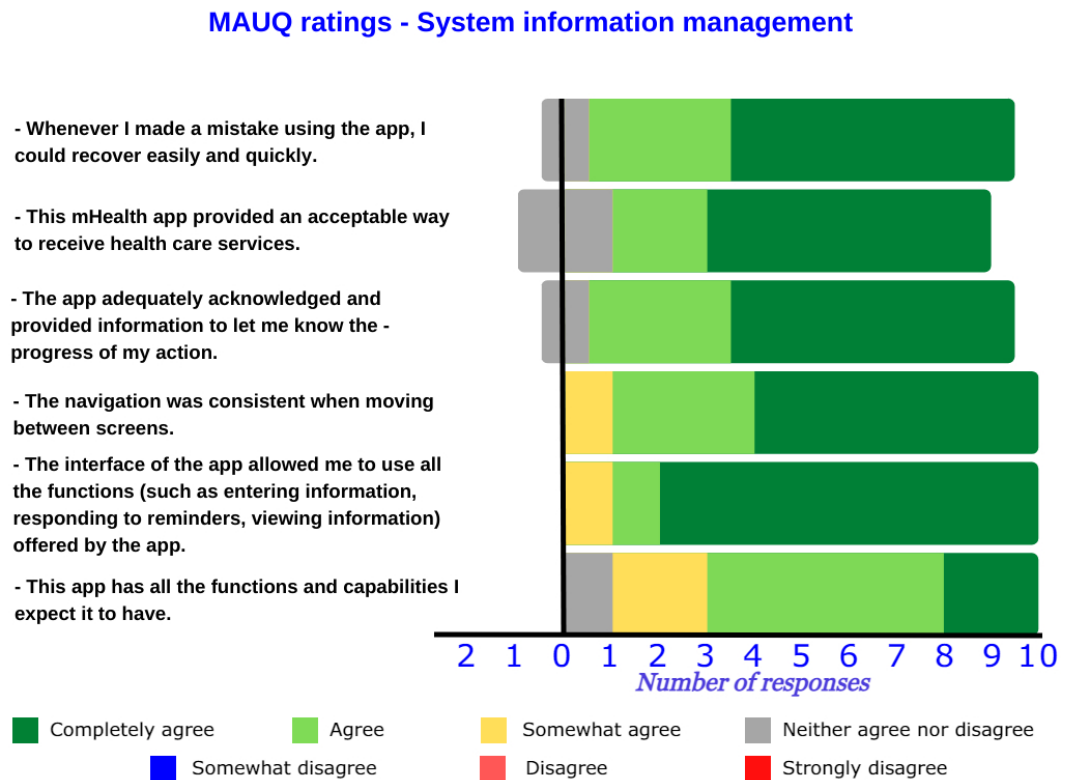


Figure 23. Ratings for the MAUQ system information arrangement statements.

The participants perceived the app as being useful, scoring a mean of 6.18/7 in MAUQ. Figure 24 represents the ratings of the 10 participants for each MAUQ statement (MAUQ statements 15-21). Despite being not fully aware how each function serves PwP as they are not real PwP, most participants described the app features as helpful and complete overall.

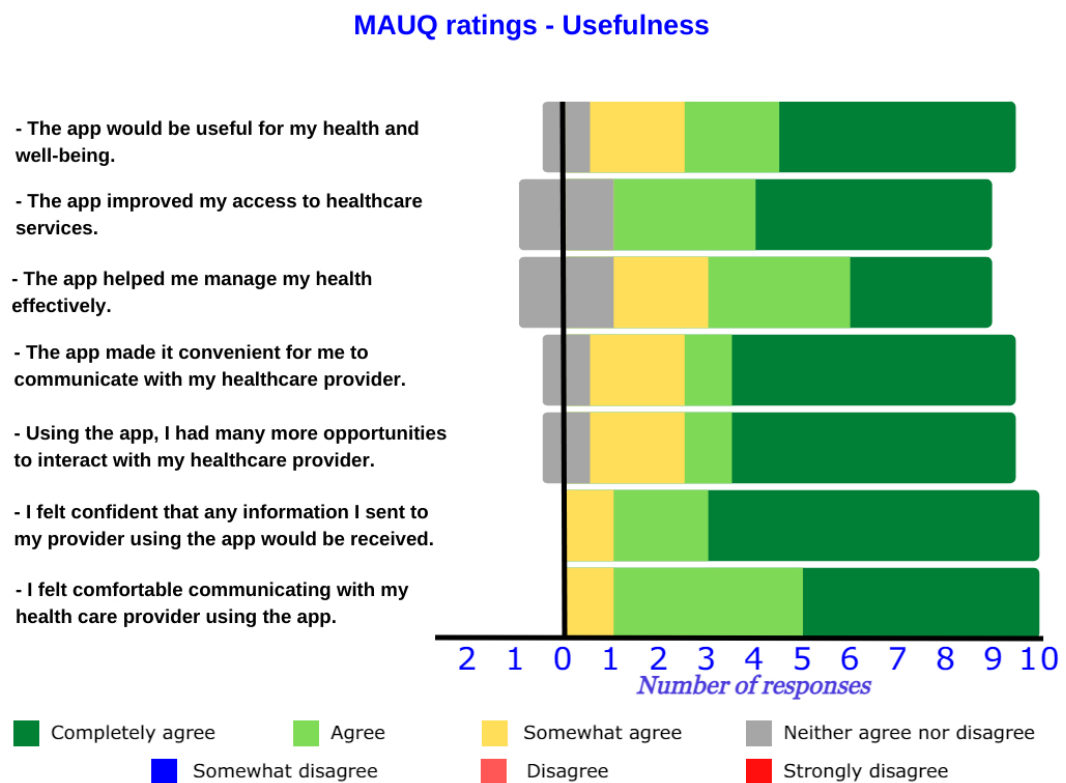


Figure 24. Ratings for the MAUQ usefulness statements.

6.2.2. Qualitative results

Half the participants reported watching the provided video about PD symptoms, while the other half have not watched the video or watched it partly. The purpose of this video was to educate the participants more about PD in addition to the provided written information in the document sent. When the participants were asked to describe how well they could imagine the life of a person with Parkinson's disease, most participants described how annoying the life of patients can be, quoting a participant: *"my experience is considered as a healthy person opinion the disease is a very challenging thing to a person to leave with. and i can't imagine someone have to live through that much obstacles that can be created by the disease. because he will feel up normality in his muscles movements and also it would be very embarrassing in many situations specially to new people"*, another participant stated: *"It is a weird life which you cannot control your nerves"*.

Three participants reported some app features that were hard to use acting in the PD persona, like hard date selection interface, difficulty to use the app with the left hand, and forgetting to record the medication on time or losing passion to record it, whereas seven participants reported no difficulties.

When asked about the usability problems they faced while acting in the PD persona and using the app, five participants reported difficulties, whereas five participants reported none. One participant reported difficulty in writing even optional comments as a PD patient, another participant reported difficulty in using the app with the left hand (acting on a persona with tremor in the right hand) as buttons were far for them. One participant considered the calendar in the dashboard to be too small for them. Another participant complained that the font was still not big enough.

Five participants reported no technical problems, however, the rest reported issues like widgets screen overflow, quoting a participant: *“There was something looks like yellow squares appear on the screen and hide some of the buttons but I think this is due to my small phone”*. Another participant was worried that they can input negative doses of boosters intakes, which is correct as the text field for boosters doses was not validated for negative numbers. Another participant reported slow loading of medication data, which I think happens when their internet connection is slow. A participant also reported difficulty in calibrating their phone fully horizontally at the beginning of the game. A big problem was reported by a participant when she lost her data after factory resetting her phone during the testing time, this is a limitation to the app at the moment as app uses the device ID which remains unchanged when reinstalling the app, but it changes when a factory reset is done.

Many suggestions and improvement ideas were stated by the participants, they include implementing an interactive help tour instead of help lines on the main screen, implementing more games to assess PD symptoms, making the app remember last open tab, using less buttons and more lists instead, and using more colors and animations in the app. Also, 5 out of the 10 participants suggested implementing a reminder for each medication group intake.

6.2.3. App features rating results

Participants rated how easy to understand and use each screen interface in the app, as well as how useful they think each feature was, the ratings for each app feature are presented in Figure 25.

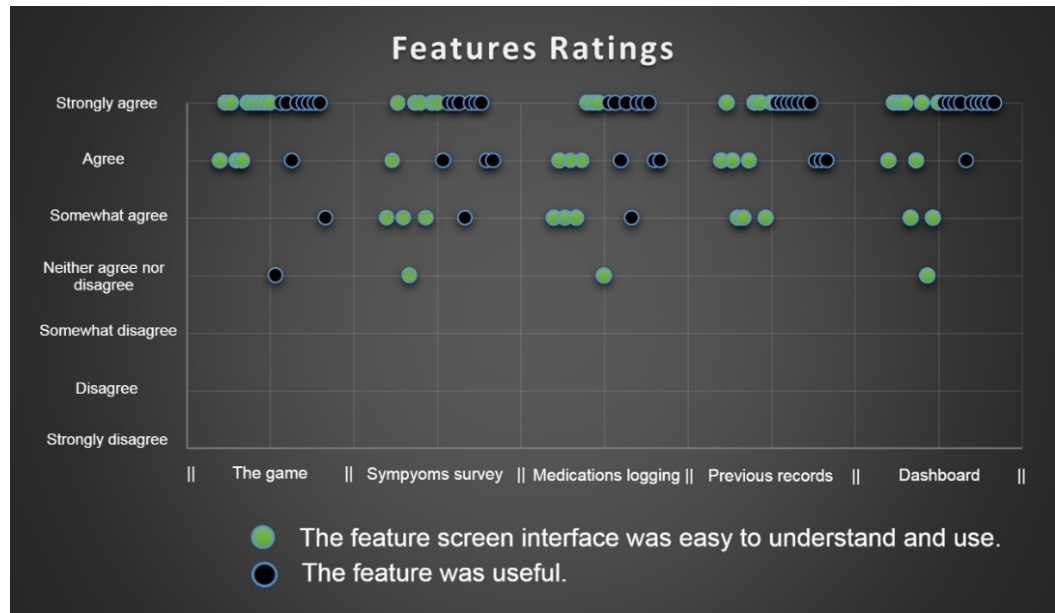


Figure 25. Rating statements made by the 10 participants for each app feature.

The game was rated to have the easiest interface to use, and the dashboard was rated as the most useful. Symptoms survey and medication logging were the hardest to use, especially because of the new idea of separated medication groups and boosters logging which could be frustrating at first, and because of the widgets screen overflow problem that was noticed to happen in these screens.

7. DISCUSSION

This thesis aims at finding a digital solution that can help PwP assess their symptoms severity regularly with ease, measure their medication adherence, and help doctors determine better future treatment plans by visualizing the patients' data. This chapter summarizes the thesis work, states its limitations, and possible future work.

7.1. Contribution

Preliminary work in the STOP app was helpful to inspire the thesis work [22][24][25][44][45][46]. The focus of this thesis was to design, implement, and test a mobile application that can fulfil the purpose mentioned, by addressing the 3 research questions that the thesis targets.

RQ1: How to keep track of PD symptoms using a smartphone?

Track Myself app has 2 elements that are designed to help track and assess symptoms for PwP, the first element is an accelerometer-based game to detect the patients' hand tremor and calculate a score accordingly, while having an easy interface for PwP. The game leverages the knowledge of previous gamification approaches made for the same purpose [18][19][24], and it was tested by 10 healthy users acting on a persona of a PD patient. The study shows that the participants rated the game to have a very good interface for PwP while being useful, some participants even suggested having more games. Validation of the game in assessing PD symptoms with actual PwP still needs to be done in the future.

The second element is a self-report symptoms survey that is filled by the participants themselves, where they rate the severity of their symptoms every day and further explain their symptoms if they want. As self-reporting of symptoms can be more important to the patient than the official severity level of a disease [26], this survey should form a better understanding of the patients' symptoms. Participants of the study reported also good usability score for this feature.

RQ2: How to track medication adherence for PwP using a smartphone?

The app has a medication journal where the patient logs their medication intakes regularly. The medication journal categorizes the medications into groups and boosters, as PwP have complex medication regimens that can require grouping. This medication history will help calculate the adherence of the patient to the medications later on. The study shows that the interface for logging the medications is fairly easy to use by PwP and still being useful in keeping an accurate medication history and calculate the patient's adherence.

RQ3: How to visualize the data collected by the app?

Three charts presenting medication time-adherence, symptom surveys, and game scores were generated for each patient, to be viewed in a dashboard application. The dashboard is hosted on webpage to be viewed by the doctors, but can be accessed by the patient directly through the app using their unique device ID. All charts' data are shown on the Y-axis, and dates of the data are shown on the X-axis, where the dates have different formats according to the selected date range by the viewer. The medication time-adherence of the patient is calculated by the difference in time between the actual and optimal time for taking their medications. A blue trendline is used in the three charts to help the viewer see the changes of the overall scores for each chart, for example, if the slope of the symptom surveys trendline has a positive slope, this indicates that the user is reporting worse symptoms level over time. The dashboard can help doctors form relations between these data and detect the problems and determine the best future treatment plan for the patient based on their data. Participants of the study reported the dashboard as the most useful feature of the app, while still being user-friendly.

7.2. Limitations and future work

There are some limitations to the study made on the app, the app was tested for two weeks by only 10 participants that are not real PwP but rather healthy people acting on a persona. They were given good amount of information about the disease through written symptoms descriptions, a video to watch, and two personas describing real life challenges of PwP, however, they are still not actual PwP after all, which encourages further testing and validation by actual PwP. For example, the game needs to be tested by actual PwP that can validate the accuracy of the game as the STOP application did [22][24]. Also, the study did not test the doctor's side of the app, which would have been beneficial specially for testing the dashboard, as feedback from a neurologist on the dashboard could help make the interface even better for them while emphasizing the most important data in their medical opinions. Some limitations of the app are the lack of user login profiles, as data for every patient depend on their device ID, the device ID remains unchanged when the user reinstalls the app, but it changes if the user does a factory reset or changes their smartphone.

Future work can start with having user profiles that are easy to login with, in addition to the device ID implemented option that does not require a user account. Also, improving the app based on the feedback received from the participants will be a good step, specially features like a reminder for each medication group sent to the user's device. To get even better feedback, the app should be tested by actual PwP as well as some actual neurologists in a future study, while planning to act on that feedback and implement the needed changes to the app.

8. CONCLUSION

Parkinson disease (PD) is a spreading neurological disorder that affects millions of people worldwide, it obstructs its patients from performing daily activities with ease. Its symptoms vary from one patient to the other, and usually assessed clinically twice a year despite varying within hours. Its treatment requires patients to be adherent to complex regimens, where this treatment need to be customized according to each patient's progress. The objective of this thesis is to design, implement, and test a mobile app named "Track Myself" that can help solve these issues. The app has an accelerometer-based game that assess symptoms severity based on the patient's hand movement. The app also includes a daily self-report symptoms survey that the patient fills to rate their total symptoms severity level and describe these symptoms. To keep track of the medication history and calculate the patient's medication adherence, a medication journal is implemented in the app for the patients to log their medication intakes regularly, which are prescribed by their doctors using the app as well. A crucial part of the app is a dashboard of three charts, representing the medication time-adherence, symptom surveys, and game scores of the patient. This dashboard can help the doctors form relations between the data in the charts and determine the best future treatment plan. A study on ten healthy participants was done on the app, the participants were asked to act in the persona of a PD patient and use the app for two weeks, where information about the disease, some life experiences from actual patients, and tasks to perform with the app were provided for these participants. A questionnaire was sent to the participants after the study, it consists of open-ended questions, rating statements, as well as a validated usability questionnaire for mobile health apps. The participants rated the app as easy to use for people with Parkinson's disease (PwP) in most features with MAUQ mean score of 6.04/7, and perceived the app as very useful in helping PwP with MAUQ mean score of 6.18/7. The game screen interface was rated as the easiest feature to understand and use, and the dashboard was rated as the most useful feature. A limitation to the app is the lack of user profiles and using only the unique device ID to manage the users' data, which can change when the user switches to another smartphone. Another limitation is not testing the app with actual PwP and neurologists that can give more valuable feedback for the app, however, this can be considered as a future plan for the app. Source code links are available in Appendix 4.

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10. APPENDICES

Appendix 1 Instructions for Track Myself app evaluation sent to participants before using the app.

"Track Myself" app evaluation

“Track Myself” is an Android app made for Parkinson disease patients for tracking their medication and symptom level. Parkinson’s disease has many symptoms, which affect their physical and mental health. To have a better idea about Parkinson disease, please watch this video:

<https://www.youtube.com/watch?v=4qdD4Ny34cc>

During this evaluation, you are asked to act in a persona, that means you should try to think and act like a person with Parkinson’s disease. We have created two personas, you can choose a character for you:

Mark: 55 years old, works as a teacher, he was diagnosed with Parkinson’s three years ago. He suffers from tremor in his right hand, and occasional stability problems. He suffers from apathy from time to time, as he is not sure how long he can cope in his work. He has to use his left hand to write with his smartphone sometimes due to the tremor symptom. He takes medications 4 times consistently every day so that he feels well before the medicine effect starts to fade. If needed, he can take an extra dose, a so-called “booster” medication, if his symptoms are bad. He wants to check if his treatment is working by playing the game, and record his daily symptoms to check for progress. He is keen to check his previous records to ensure he didn’t forget any medication dose through the day.

Emma: 60 years old, she is a retired nurse. She was diagnosed with Parkinson’s seven years ago, and she has mild tremor in both hands, and she suffers from stiffness and slowness of movement. Due to stiffness, she has to use voice command to take a photo with her smartphone. She has problems in hitting the buttons, and often she makes many mistakes when writing, and that is why she has to use a fingerprint to log in to her phone instead of a pin code. In addition to Parkinson’s, she has other conditions to treat with medication, hence she takes medications 4 times per day. If she has pain, she takes a painkiller as a “booster” medication. Sometimes she forgets if she took some medication or not, and if she misses a few medications, she cannot write an SMS due to the symptoms. So she wants to record all these medications through the app instead of the old pen and paper method she used to do with herself and with patients she treated. She also wants to try the game and see if taking her medications on time will make her symptoms less by time.

Please try to act like them as much as possible while using the app.

Tasks for participants:

1. **Watch the video about the symptoms.**
2. **Install the app you find in the same Google Drive folder you received (by pressing on the ‘track-myself.apk’ file) on your Android phone.**
3. **We need to load the doctor’s prescriptions (because for evaluating the app we will test only the patients’ side). So do this after installing the app (ONLY ONCE): Go to ‘More’ then ‘Settings’ then press ‘Load doctor’s prescriptions’ while having Internet access to your phone.**
4. **Please perform these tasks daily while having Internet access to your phone:**
 - Play the game 3-5 times every day and submit the score, change the game settings every now and then.
 - Fill in the symptoms daily survey (preferably once at the end of every day) using the daily survey button, or by clicking on the daily survey reminder you receive daily around 8 PM.
 - Input the list of 4 medication groups as close to their optimal times as possible:
 - Morning (optimal time is 10:00)
 - Afternoon (optimal time is 14:00)
 - Sunset (optimal time is 18:00)
 - Night (optimal time is 22:00)
 - Input 1 or 2 random booster medications at any time during the day (you will find a list of 8 booster medications), through ‘Medication’ then ‘Add booster instead’.
5. **Every now and then, check the previous records for medication groups, booster medications, daily surveys, game scores from the ‘More’ menu and delete some records if needed.**
6. **On the last day of the 2-week trial period, try intensively the ‘Dashboard’ you have in the ‘More’ menu, that shows all your previous records in graphs with respect to time.**
7. **After the trial period, give feedback about the app by answering the questionnaire I will send you.**

If you have a question or would like to add a comment before the 2-week trial ends, please use the Google Sheets file named ‘Questions, answers, and comments’ you find in the Google Drive folder. If you encounter any difficulties, please contact me at: fady.tawfeek@student.oulu.fi

This app does not take access or permissions to anything in your phone (storage, location, etc...) so no worries.

Thank you!

Appendix 2 Questionnaire sent to the participants after using the app, including MAUQ and my own questions, adapted from Google Forms to match the thesis guidelines.

'Track Myself' app evaluation

'Track Myself' is a mobile app for Parkinson's disease patients to measure their symptoms, as well as tracking the patients' medication adherence. You have been using the app for 2 weeks now and now we invite you to share your experiences about using the app. The information that you provide will be used for the purposes of academic studies and publications. Participation in this study is not compensated. There are no social or legal risks beyond answering this questionnaire. Your data will remain 100% anonymous. Your participation is voluntary and you have the right to withdraw your consent or discontinue participation at any time. Time needed for this questionnaire is approximately 15 minutes. If you have any questions about this study or if you wish to delete your data later, you may contact Fady Tawfeek, at fady.tawfeek@student.oulu.fi. In the point of view of the persona you acted on, please answer the next questions considering the Track Myself app and the dashboard you used for 2 weeks.

Thank you in advance!

*** Required**

1. Do you consent to using the data you submitted with the app and your answers to this questionnaire anonymously ? *

☐ Yes ☐ No (please note that this will end the questionnaire to this point.)

Personal information:

2. Name *

3. Age *

4. Email address *

5. Your Device ID (in the app, from 'More' then 'Dashboard' then under 'Device ID' then type it here) *

6. Did you watch the provided video on Parkinson's symptoms ? *

☐ Yes ☐ No ☐ Partly

7. Which persona did you act on ? *

☐ Mark ☐ Emma

8. Please describe your experiences on how well you could imagine the life of a person with Parkinson's disease? *

9. Which app features were hard to use acting in your persona? *

10. What usability problems did you face acting in your persona while using the app? *

11. What were the technical problems you faced while using the app? *

12. Are there any features you wish they were in the app? Suggestions and improvements? *

Please rate the next statements.

In this questionnaire, 1 - strongly disagree, 2 – disagree, 3 – somewhat disagree, 4 – neither agree nor disagree, 5 – somewhat agree, 6 – agree, 7 – strongly agree.

Ease of use and satisfaction:

13. Game screen interface was easy to understand and use. * 1-7
14. Daily symptoms survey interface was easy to understand and use. * 1-7
15. Medications screen interface was easy to understand and use. * 1-7
16. Previous records pages interface was easy to understand and use. * 1-7
17. Dashboard interface was easy to understand and use. * 1-7
18. Buttons sizes were big enough, and there was minimal to no scrolling needed in the app. * 1-7
19. Font size was big enough also for the elderly. * 1-7
20. The app was easy to use. (MAUQ 1) * 1-7
21. It was easy for me to learn to use the app. (MAUQ 2) * 1-7
22. I like the interface of the app. (MAUQ 3) * 1-7
23. The information in the app was well organized, so I could easily find the information I needed. (MAUQ 4) * 1-7
24. I feel comfortable using this app in social settings. (MAUQ 5) * 1-7
25. The amount of time involved in using this app has been fitting for me. (MAUQ 6) * 1-7
26. I would use this app again. (MAUQ 7) * 1-7
27. Overall, I am satisfied with this app. (MAUQ 8) * 1-7

System information arrangement:

28. I got the reminder notification on the daily symptom survey everyday. * 1-7
29. Loading time was short in most features. * 1-7
30. Whenever I made a mistake using the app, I could recover easily and quickly. (MAUQ 9) * 1-7
31. This mHealth app provided an acceptable way to receive health care services. (MAUQ 10) * 1-7
32. The app adequately acknowledged and provided information to let me know the progress of my action. (MAUQ 11) * 1-7
33. The navigation was consistent when moving between screens. (MAUQ 12) * 1-7

34. The interface of the app allowed me to use all the functions (such as entering information, responding to reminders, viewing information) offered by the app. (MAUQ 13) * 1-7

35. This app has all the functions and capabilities I expect it to have. (MAUQ 14) * 1-7

Usefulness:

36. The game in the app is useful for determining the severity of PD symptoms. * 1-7

37. The daily symptoms survey is useful for determining the severity of PD symptoms. * 1-7

38. The medications input in the app is useful for tracking the medications adherence over time for patients in general. * 1-7

39. The previous records part in the app is useful for tracking patients' data over time. * 1-7

40. The dashboard is useful for summarizing data for patients and making relations between different patients' records. * 1-7

41. The app would be useful for my health and well-being. (MAUQ 15) * 1-7

42. The app improved my access to healthcare services. (MAUQ 16) * 1-7

43. The app helped me manage my health effectively. (MAUQ 17) * 1-7

44. The app made it convenient for me to communicate with my healthcare provider. (MAUQ 18) * 1-7

45. Using the app, I had many more opportunities to interact with my healthcare provider. (MAUQ 19) * 1-7

46. I felt confident that any information I sent to my provider using the app would be received. (MAUQ 20) * 1-7

47. I felt comfortable communicating with my health care provider using the app. (MAUQ 21) * 1-7

Appendix 3 Feedback from the participants on the 5 open-ended questions.

Please describe your experiences on how well you could imagine the life of a person with Parkinson's disease?

"No very well. It was somewhat difficult, but doable."

"I haven't met someone with the disease before, but I can image it is a serious disease that makes life hard."

"It is a weird life which you cannot control your nerves"

"hard life which you can't hold something as normal as anyone else"

"Hard to represent but must be annoying for mainy daily life activities"

"I think it's not easy to have parkinson's disease because it makes you unable to do the normal daily tasks, you are required to take a lot of medications or otherwise you will face violent symptoms"

"It was so good especially the game"

"I don't know much"

"my experience is considered as a healthy person opinion the disease is a very challenging thing to a person to leave with. and i can't imagine someone have to live through that much obstacles that can be created by the disease. because he will feel up normality in his muscles movements and also it would be very embarrassing in many situations specially to new people."

"I could imagine it's a really frustrating life"

Which app features were hard to use acting in your persona?

"Symptom survey comments. Date selection."

"None"

"Sometimes I forget to record the medication on time or lose passion to record it"

"None"

"No real issues"

"there was nothing hard to use because the items were very obvious and it was easy to choose the icons you want without confusion"

"Using the left arm"

"Nothing"

“actually once i have read the documentations i haven't faced any problems dealing with the app”

“None”

What usability problems did you face acting in your persona while using the app?

“Writing comments.”

“- The Symptoms severity buttons could be made easier to use (using colors to indicate severity for example) - Instead of giving the option to use booster if medication is not inserted on time, the app should detect this, and give you the booster option if the medication is not on time. - Fonts could be larger. - More colors, creative art and animation.”

“The buttons that are on the right side because acting as mark I have tremor in my right hand so I only use the left hand and sometimes the buttons are far”

“acting as Emma I couldn't choose the date in the dashboard well; the calender was too small. I forget to open the app”

“None”

“I think sometimes i needed a reminder or alarm for my medicine time because i always forget to take my medicine”

“Nothing”

“Nothing”

“i haven't faced any.”

“None”

What were the technical problems you faced while using the app?

“None.”

“None”

“There is nothing”

“There was something looks like yellow squares appear on the screen and hide some of the buttons but I think this is due to my small phone”

“Its possible to input negative amount of boosters”

“there was no problem and it was easy to use”

“Their is no one”

“My information were lost when I factory reset my mobile”

“some times i faced obstacles to deal with the app when playing the game because it's very hard to determine the horizontal stability while holding the phone in normal condition”

“Uploading the medication data”

Are there any features you wish they were in the app? Suggestions and improvements?

“No. It was pretty good overall.”

“- More than 1 game. - I think main tab should be medication insertion?, even better app remembers the last open tab and show it on start.”

“If the app has a reminder it will be better in use”

“The option of the reminder will be helpful for patients as Emma”

“- Maybe reduce number of buttons and use lists instead (e.g. for symptoms) - More menu might be too dense, regroup some data? - Implement an interactive help to make a tour of the app could be useful for persons with Parkinson diseases since they are usually not proefficient with smartphones (instead of lines of help on the main screen)”

“In my opinion it would be better to add an alarm or a reminder for the medicine time reminder for every medication”

“Nope”

“i wish there would be a reminder about the medication time because many times i forgot the medication times to log it into the system.”

“Nope”

Appendix 4 App links.

Adobe XD design: <https://xd.adobe.com/view/8d4ca465-2983-4aa6-95d4-8b535fe6906f-d81f/>

Track Myself source code: <https://github.com/FadyTawfeek/track-myself-flutter-app>

Dashboard source code: https://github.com/FadyTawfeek/Dashboard-Track_Myself

Dashboard live link: <https://fadytawfeek.shinyapps.io/Track-Myself/>