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Designing a platform for the clinical assessment of Parkinson's Disease with inertial sensors

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Author

César Mendes

To everyone who keeps battling the disease.

Resumo

Parkinson é o segundo distúrbio neurodegenerativo mais comum relacionado com o avanço da idade, cerca de sete milhões a 10 milhões de pessoas em todo o mundo têm Parkinson. Estudos indicam que apenas nos países da zona ocidental da Europa existiam entre 4.1 a 4.6 Milhões de indivíduos com Parkinson com uma idade acima dos 50 anos em 2005 e estima-se que este valor vai duplicar para quantidades entre 8.7 a 9.3 Milhões até 2030[7].

Uma vez que o parkinsonismo é uma doença sem cura e cujo acompanhamento constante é essencial, são necessárias ferramentas que ajudem no acesso à condição dos pacientes e na sua avaliação. Os pacientes com doença de Parkinson (DP) apresentam problemas de estabilidade e isso afeta várias tarefas no seu cotidiano, os sintomas da DP podem ir de tremor, extrema lentidão e instabilidade postural ao comprometimento da função cognitiva, fala, deglutição ou sono, entre outros.

O desafios para a avaliação clínica de pacientes com Parkinson, englobam a compreensão da progressão da doença, as respostas às intervenções farmacológicas e não farmacológicas e as flutuações sofridas pelos pacientes. No entanto, a quantidade de informação disponível para os clínicos avaliarem ainda é escassa hoje em dia.

As avaliações a pacientes com Parkinson são feitas durante consultas clínicas que podem perder as flutuações existentes durante o dia devido à natureza altamente variável desta doença que difere de paciente para paciente e que muda ao longo do dia. Ainda assim, é importante estar ciente da evolução da capacidade física dos pacientes com doença de Parkinson; É impossível avaliar uma compreensão mais profunda da progressão da doença com as abordagens tradicionais usadas nos prestadores de cuidados de saúde comuns.

Abordagens tradicionais de acompanhamento a pessoas com Parkinson em ambientes clínicos são normalmente realizadas recorrendo a um conjunto de escalas e perguntas, o que origina um conjunto de informações subjetivas referentes ao paciente e que podem ser enviadas consoante o clínico que esteja a executar a avaliação. Existem, no entanto, consultas que recorrem a testes funcionais como: executar um certo exercício repetidamente ou movimentar-se de um local para outro; originando igualmente dados subjetivos devido aos métodos que são utilizados pelos clínicos, que vão desde a utilização de um cronómetro a avaliação visual.

Atualmente, ainda há dificuldade em analisar a progressão de pacientes com Parkinson durante consultas médicas, devido aos mecanismos existentes utilizados para a análise serem subjetivos ou caros, o que significa que apenas alguns médicos são capazes de fornecer métricas objetivas aos seus pacientes. No entanto, há um interesse crescente em ter avaliações objetivas na doença de Parkinson e nos últimos anos o uso de dispositivos baseados em tecnologia no tratamento da DP tem sido apontado como uma tecnologia de ponta na medicina moderna.

Existem muitos fatores que facilitam e apoiam o uso da tecnologia no monitoramento de Parkinson, bem como a existência de dispositivos tecnológicos médicos no ambiente de laboratório, o crescente acesso à Internet de alta velocidade que leva a uma transmissão de dados mais fácil e rápida entre os dispositivos, as conexões entre os dispositivos e também o aumento da alfabetização da população em geral quanto à tecnologia.

Do ponto de vista dos pacientes é importante existir uma forma de traduzir informação entre clínicos e pacientes de modo a que cada indivíduo obtenha um conhecimento mais rico da sua doença e da evolução da mesma, em vez de aceitar incontestavelmente a execução de tratamentos indicados pelos clínicos.

Este projeto consiste no desenvolvimento de uma plataforma baseada em demonstração de dados que visa apoiar os clínicos na avaliação física de um paciente com Parkinson durante consultas clínicas. A plataforma servirá como ferramenta de suporte para os médicos, de modo a avaliar o progresso dos pacientes e assim providenciar um diagnóstico mais dinâmico e preciso com base nos exercícios que se realizam durante as consultas médicas sendo possível, posteriormente, comparar os resultados com os anteriores.

O projeto está dividido em três partes principais, um estudo inicial onde enriquecemos o conhecimento de como funcionam as avaliações executadas a pacientes com Parkinson e decidimos a melhor forma de apresentar os dados aos clínicos e pacientes seguindo uma abordagem de co-design com médicos e pacientes. Para conseguir adquirir os conhecimentos necessários foram realizados grupos de foco e sessões de observação em contexto de avaliação clínica.

A segunda fase consiste na implementação da aplicação web Datapark e dos seus algoritmos de modo a obter métricas objetivas dos exercícios realizados nas consultas médicas pelos pacientes e de uma aplicação móvel utilizada para guiar e ajudar os clínicos nas avaliações realizadas. A plataforma funciona como um ponto central que integra dados recolhidos a partir da aplicação móvel e métricas objetivas obtidas a partir de um acelerómetro colocado no paciente durante a sua avaliação.

Durante as avaliações clínicas o risco de queda dos pacientes é evidente, o que leva à necessidade de uma maior atenção e cuidado por parte do clínico, que ao mesmo tempo, é apoiado pela utilização de outros objetos e dispositivos para executar toda a consulta. A aplicação móvel tem como fim guiar os clínicos nas consultas médicas tal como o

métodos tradicionais já utilizados. No entanto, a aplicação engloba num só dispositivo todas as funcionalidades necessárias para não existir necessidade do clínico se concentrar em nada mais senão no paciente que está sob avaliação.

A terceira e última fase do projeto consiste na avaliação da plataforma com médicos e pacientes, para este fim foram realizados dois estudos em ambiente real. O primeiro estudo teve duração de uma semana com a participação de três clínicos e de sete pessoas com Parkinson, servindo para dar a entender a utilidade da plataforma e a possibilidade da inserção desta ferramenta no ambiente clínico, tendo em conta quais as melhorias aplicáveis.

O último estudo realizado foi um estudo longitudinal com o objetivo de validar a plataforma e assegurar a sua utilidade a longo prazo, para isso, o sistema foi deixado em funcionamento sem interrupções durante dois meses. Durante este tempo foram avaliados onze pacientes diferentes, sendo cada um deles avaliado pelo menos duas vezes por um dos quatro fisioterapeutas que participaram nas avaliações.

Este estudo terminou com um questionário feito aos fisioterapeutas com o objetivo de avaliar a usabilidade e validade da plataforma, providenciando indicadores de que o Datapark pode ser útil. A noção de que a aplicação móvel tem valor suficiente para substituir os métodos de recolha e anotação de informação tradicionais foi assim extraída.

No entanto, para remoção total dos mecanismos tradicionais e utilização única da plataforma encontrou-se a necessidade de continuar a iterar e melhorar o sistema. Desta forma, é necessário fornecer melhores relatórios e melhorar a usabilidade, culminando por fim na plataforma visada que possui centralmente todos os mecanismos fulcrais para avaliar doentes com Parkinson.

Depois de concluído este projeto, a plataforma não tem apenas uma zona para controlo de Parkinson baseado em contexto clínico, mas também uma área para verificação do dia-a-dia dos pacientes. Existe também uma terceira área cuja função será obter dados subjetivos dos pacientes durante o dia-a-dia com o intuito de oferecer aos médicos um melhor controlo da evolução desta patologia em cada um dos pacientes.

Finalmente, o sistema desenhado como solução para este problema para além de ter sido utilizado para os estudos descritos, encontra-se neste momento num estado estável e está em funcionamento, sendo possível a quem estiver registado no nosso sistema executar avaliações utilizando qualquer uma das ferramentas apresentadas.

Palavras-chave: Consultas médicas orientadas a dados, acelerometria, Doença de Parkinson, algoritmos, avaliações clínicas

Abstract

Parkinson's is the second most common age-related neurodegenerative disorder, an estimated seven million to 10 million people worldwide have Parkinson's disease. Since Parkinsonism is a disease without cure and whose constant monitoring is essential, tools that help in the access to the condition of the patients and their evaluation are necessary.

This project consists on the development of a data-driven platform that aims to support clinicians in physical assessment of a patient with Parkinson's during clinical appointments. The platform will serve as a support tool for clinicians to evaluate the progress of their patients and thus give more dynamic and accurate diagnosis based on the exercises that they perform during their appointments and thus compare the results with the previous ones.

The project is divided into three main parts, an initial study where we will decide how best present show the data to clinicians and patients, following a co-design approach. A second phase will be the implementation of the platform and its algorithms to obtain metrics of the exercises performed in appointments, by the patients. The third and final phase of the project consists on the evaluation of the platform with clinicians and patients.

After completing this project, the platform not only has a Parkinson's control environment based on clinical context analysis but also an area for free-living Parkinson's verification. It is also included a third area whose function is to obtain patients' subjective data during their daily life in order to give clinicians a better control the evolution of this pathology in each patient.

Keywords: Data-driven medical consultation, accelerometry, Parkinson's disease, algorithms, clinical evaluations

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Chapter 1

Introduction

Parkinson's is a neurodegenerative disease that affects the mobility and the autonomy of its bearers. Nowadays it affects around 4.8 Million people in Western Europe and it will continue to grow with the population aging [7]. Patients with Parkinson's disease (PD) have stability problems and this affects several tasks in their daily lives, PD symptoms can go from tremor, extreme slowness and postural instability to impairment of cognitive function, speech, swallowing or sleep, among others.

Challenges for clinical practice include understanding the progression of the disease, the response to pharmacological and non-pharmacological interventions, and the variations the patient goes through alongside their possible explanation. However, the amount of information available to clinicians to make their assessments is scarce.

The most significant and essential clinical sign that leads to parkinsonism diagnosis is Bradykinesia. It implies abnormal function in certain neuronal circuits that lead to a disorder of the patient motor function manifest as slowed, small-amplitude movements. The clinical recognition of this health condition requires the observation and identification of these fluctuations that may affect limb control, gait or posture.[27]

Assessments for PD are made during clinical appointments which can miss the fluctuations existent during the day due to the highly variable nature of this disease that differs from each patient and that changes during the course of the day. Still, it is important to be aware of the evolution of the physical capability of the PD patients; a deeper understanding of the progression of the disease is impossible to be assessed with the traditional approaches that are used in the common health care providers.

Evaluations of parkinsonian patients is mostly performed at appointments, which are not frequent, and mostly based on functional tests like standing from a chair and sitting repeatedly and even walking between the two posture transitions with subjective assessments made by the clinicians using a stop-watch approach or by visual evaluation, which leads to an even more subjective outcome.

1.1 Motivation

Nowadays, there is still difficulty in analyzing the progression of patients with Parkinson's during doctor's appointments because the mechanisms that exist to analyze it are either very subjective or expensive, which means that only few clinicians are able to give objective metrics to their patients. However, there is a growing interest in having objective assessments in the Parkinson's disease and in the last years the use of technology-based devices in the PD treatment has been pointed as a cutting-edge advance in the modern medicine. [14]

Many factors facilitate and support the usage of technology in the monitoring of the Parkinson's, like commonly existence of medical technological devices in the lab-environment, and the growing access to high speed internet which leads to an easier and faster transmission of data between devices and the connections between devices and also the rising of computer literacy of the general population.

From the point of view of the patient, it is important for them to understand and have something that works like a translator between clinicians and themselves; most of the time the objectives and the treatments given by the clinicians are accepted blindly by the patients. The existence of something that connects them and makes it possible for a patient to understand his own disease evolution helps in the conversations between him and the clinician and strengthen their relation and consequently their communication. [17]

In this project, we will focus on offering a new way of analyzing the progress of Parkinson patients using a data-driven health care platform based on data obtained from in-the-lab exercises.

1.2 Context

This master's thesis was developed at LASIGE¹, which has a known and extended experience with accessibility and ageing projects [24, 20, 5].

These prior projects allowed the department members to enrich their knowledge about, dementia, aging and health and implicitly facilitate the introduction and awareness of the Parkinson's disease assessment, treatment and monitoring keeping track of people's difficulties and limitations when under this condition.

Over the last years a relationship between LASIGE and CNS² (Campus Neurológico Sénior), a neurological rehabilitation center has grown and my thesis was made in cooperation with their clinicians and patients to validate and test my solution. This agreement results on a beneficial impact to both parts due to the search to modernize the evaluation of patients with this impairment using technology, leaving behind the known traditional

¹<http://www.lasige.di.fc.ul.pt/>

²<http://www.cns-campus.com/>

methods from their part and to use a globally known rehabilitation center and its professional clinicians as testers of my solution for this study.

The offered solution of this study was developed cooperatively with another two students also working to complete their master's. Thus, without one of us the whole app/solution would not work and the whole project would not succeed, therefore, this project is divided in two major apps: Datapark Web App that its implementation was made by the team and the Datapark mobile that was all implemented by me during the course of my thesis.

From now on in this document, the pronoun 'we' will refer to the work done as a team, and 'I' means the main work of this thesis: the creation of tools to evaluate clinically patients with Parkinson's and present it as meaningful data to the clinicians.

1.3 Research goals

The goal of this project is to enable clinicians to objectively measure functional outcomes in clinical appointments, resorting to inertial sensors, and thus allow a more thorough awareness of patient evolution. To achieve this goal, we will:

1. Understand together with clinicians and patients the exercises and information they want to see presented and how;
2. Develop a platform that is able to present relevant information from raw inertial data.
3. Evaluate the preliminary perceived impact of such platform in real-life clinical settings.

1.4 Approach

For the objective of this thesis, it was possible to divide the whole process in three phases:

- Preliminary study: First phase of the project where the objective is an in-depth understanding of the current practices and methods to deal with Parkinson's in-the-lab. Thus, this stage is divided in literature review of existent solutions and focus groups with medical staff and patients.
- Platform and Algorithm implementation: This is the second phase and as the name implies, the period where I was focused in the implementation of the medical platform. At this time, the problem is well defined and the solutions are listed, therefore, the emphasis is on the application of this solution in the medical platform where it is going to be possible to see the progress of a Parkinson's patient using data recorded

from an accelerometer, previously chosen (AxivityAX3), and processed using state of the art algorithms, that will be implemented in the platform itself.

- **Platform assessment in clinical context:** The last phase of this project is the platform use in medical context with clinicians and patients, thus, this is a core step in the project because is where we will understand what was truly important and which are the despicable factors of the platform, possible leading to a rework on the system with the intent of improving the platform performance in clinical context.

The data-driven platform for Parkinson's treatment will not only evolve the in-the-lab assessment that was previous described but also two more extensions, a scope for free-living data of Parkinson's patient and another one to subjective collected data, also in free-living. Thus, the data-driven platform will integrate three separate studies in only one platform to improve the clinicians' diagnoses.

1.5 Contribution

Currently, Parkinson's is a health condition where professionals from my area usually do not have contact with. Also, clinicians who monitor and keep track of patients porting this disease, are not commonly using new and cutting-edge software provided by researchers trying to improve their area. Although, these two areas were never so close as they are now.

During the execution of my thesis my contribution was not only what I developed but the integration of new knowledge from the medical area in the engineering course pool, as well as the insertion of new evaluations, methodologies and knowledge in the medical field:

- **Requirements collection and environment involvement** next to 5 health professional, psychologists and physiotherapists with different backgrounds, during multiple sessions of discussion and interviews about the current ways of monitoring Parkinson's that led to different conclusions that result from the distinct natures from each clinician.
- **A web application and a mobile application co-designed with clinicians** - used to generate meaningful reports used to evaluate the patients after they perform their clinical assessments where the clinicians are using the mobile application that allow clinicians to primarily focus the attention on the patient during the execution of the tasks without the distractions of using papers or chronometers.
- **Validation of the new technology** by those who evaluate patients with Parkinson's daily which are accustomed to the tasks used to the evaluation and also by those

who start the evaluations soon in their career, with around 20 patients bearing this disease the evaluations were different and dissimilar outcomes resulted from them giving me enough information to improve and update both technologies.

- **Provision of the application for longitudinal use** of the clinicians involved during the validation phase and for those who want to start evaluating patients with our system, providing a tool that is used not only for the studies but also during long term evaluations so we can see the evolution of its usage and improve its components usability and interface. Our platform has been fully adopted for usage at CNS.

1.6 Collaborations

During this project, we were involved in two events with the purpose of publicizing the project and demonstrating how it can help the evolution of Parkinson's patients' treatments:

- Participation in the "Tecnologia e Doença de Parkinson?" (Technology and Parkinson's Disease) congress held at CNS (Torres Vedras, Senior Neurological Center on 07/04/2018)
- Participation in the "Encontro com a Ciência e Tecnologia em Portugal" (Lisbon, Lisbon Congress Center, 04/07/2018)

Chapter 2

Literature Review

2.1 Clinical Assessment of patients with Parkinson's

Parkinson's control is indispensable to guarantee a quality ageing of those who have this disease. The Parkinson's control made in laboratory with the medics and patients is still quite rudimentary using basically questionnaire based assessments and traditional reporting systems during clinical visits to measure physical capability [25] and which is an inaccurately way of measuring it that leads to a heterogeneity of outcomes and reports.

Later, clinicians started to use some exercises to measure the physical health of the PD patients, Postural control and Timed Up and Go (TUG) were two of the exercises that proved to be able to quantify PD. The Balance or Postural Control is the basis of our ability to stand and walk independently as defended by [19], which indicates that the deterioration in the postural control due to the PD and ageing is correlated with an increase in risk of falls during free living. It is crucial to control the state of the postural balance in PD patients to verify the progress of the disease and the effects of the medication taken. Another example is the [8] research, the study was about the Balance Dysfunction (BD) in Parkinson's Disease as they investigated the suitability of quantitative posturographic indicators to identify patients that could develop disabling BD earlier. As it is known that the BD is one of the most common characteristics of Parkinson's bearers. Once more, BD is a disability symptom that predisposes PD patients to fall, so he defended that it is important to measure and evaluate the BD of each patient to understand the evolution of the PD and the result of the medicine taken. That intake medicine it is possible to lead to an increased postural sway in patients, as an example the treatment with levodopa. In [8], 29 PD patients and 12 control subjects were recruited and they were tested using a posturographic platform (PP) with open eyes and perform a counting exercise (which they define as a simple cognitive exercise). After their trials, the postural data was analysed and they found that patients had higher values of total standard deviation of body sway and along the Medio-lateral (ML) axis during OE condition. Besides, they concluded that the BD in PD patients can be discovered before its appearance using their methods.

It is important to understand that TUG involves a sequence of a group of exercises that for themselves also work to measure physical capacity of the PD subjects, Sit-Stand, locomotion and Stand-Sit. For example [3] defended that the isolated clinical balance tests cannot predict falls in PD. It is pointed out that it could be because of the isolation of the exercises, so he presented the MTT (Multiple Task Test), a new balance tests that consists in a sequence of tasks and simultaneously assesses multiple components of postural control.

In Bloem[3] study 50 young control subjects, 20 elder and 20 PD patients participated. The subjects had to complete the MTT which they defend that represents situations in the free-living and should be able to be done without any major equipment. For the MTT were selected risk factors associated with the falls in elderly that could be transformed into functional tasks to be completed by the subjects in clinical environment. The previous selected risk factors were then converted into different test components as motor, cognitive, visual or mixed, which lead to the creation of 8 different tasks: Standing Up, Undisturbed Walking, Turning Around, Sitting Down which we can logically compare to the TUG test but split in the 4 phases, Avoiding Obstacles, carrying empty tray, carrying loaded tray, slippery shoes, tipping the floor and reduced illumination.

The subjects completed 2 experiments, in the first experiment all 50-young control, 13 elders and 13 patients completed all the tasks, which were always the execution of the 4 TUG phases and adding 1 more task in each of the 8 trials made. In the second experiment with the purpose of studying the influence of learning through practice. Seven elderly controls and seven PD patients performed a short version of MTT, which corresponds only to the second task (TUG and answering questions), fifth task(avoiding obstacles and carrying a loaded tray), and the eight (touching floor, wearing slippery shoes and reduced illumination).

After this study Bloem concluded that 62% of control groups performed all eight consecutive tasks without errors in the motor component while only 8% of the PD patients were able to do it.

The difference between patient and controls faded away when the cognitive component was added to the score because controls made more cognitive errors than PD patients. Concluding the study, the MTT was able to discriminate between healthy and PD patients which leads to the conclusion that the sequence of exercises can show more information than the execution of each of them separately and that is why TUG exercise can show information that Sit-Stand, Walking and Stand-Sit isolated cannot show.

Recent studies show that measuring characteristics of gait is also becoming increasingly important to determine many facets of health. In [18] research, they have adopted the concept of the “Healthy Ageing Phenotype” (HAP) which is a simple and reliable measure of how healthily someone is ageing. The study aimed to recognize the most important features of the HAP and identify tools for measurement of those features. A set

of (bio)markers were proposed in this study for the physical capability, which is one of the 5 domains that characterize the HAP, we can connect each one of the most common exercises that the clinicians are using to measure the PD progression to the HAP physical capability domain which needs to assess Strength, Dexterity, Endurance, Balance and Locomotion of the PD subjects.

As seen previously, the common measures of physical capability include time tests, measured with a stopwatch, such as: Sit-Stand, Endurance, TUG and Balance, these tests were able to predict health with ageing as [13] introduced. However, these tests were measured using a stopwatch approach which causes, once more, the inaccuracy of measures due to the need to mark the beginning and the end of the exercise. Thus, this leads to different results in the outcomes and therefore lacks in consistency making it impossible to show statistics with the results. Therefore, this situation results in an increased use of non-wearable and wearable devices to quantify the physical capacity of patients with Parkinson's.

It is important to mention that the National Institutes of Health (NIH) proposed and offered to the scientific community a set of tests for the assessment of motor functioning across the life course to be used for the range of 3-85years (NIH Toolbox). The NIH Toolbox consists in a set of instruments to measure not only the motor component but also cognitive, sensory and emotional functions that have been available for free in order to define a standard set of measures to be used and facilitate the comparison of results [10].

In [13], they connected the NIH motor component tests with the physical component of the HAP, using NIH tests to measure physical capability of healthy older adults, they defined the HAP assessment with the following tests:

- Postural control, standing balance: Consists in a sum of five tests, each one with the duration of 50seconds without shoes and with arms folded across their chest, the exercise included variations at the level of the surface (Flat or Foam), at the feet distance (feet together or tandem stance) and at the eyes closure (eyes open or eyes closed).
- Locomotion: Participants had to walk 4m (x2) between two points previously marked.
- Endurance: A test where each participant walked constantly as fast as they could for 2 minutes.
- Lower limb strength: Where each participant performed repeated sit-to-stand-to-sit (x2) with their arms folded across their chests.
- Lower limb strength and locomotion: The last task was the TUG exercise, 3 trials, where after the sit-stand each participant walked 2 meters around a cone and went

back to the chair. In the section below of this chapter we will see what were the metrics obtained in these tests and the best algorithms for each one of them as well.

2.2 Devices to measure physical capability

2.2.1 Non-Wearable devices

Recent studies, as we discussed before, show that the usage of devices to measure some of the previous exercises are able to obtain the characteristics of physical capacity of the patient. GaitRITE, as an example, is a laboratory system that assess the gait characteristics of a patient and has been validated previously [23, 2]. For example, at [23] study, the purpose was to determine the validity of the GaitRITE System in detecting footfall patterns and selected gait characteristics of person with early stage PD. This research also investigated whether the Functional Ambulation Performance (FAP) scoring system is a valid tool to distinguish between selected gait characteristics of patients with early stage Parkinson's disease and similar age of non-impaired individuals.

The realization of this study had 22 volunteers, 11 with idiopathic PD and 11 with no history of neurological disorder. Each participant was asked to walk at his preferred walking speed across the carpeted GaitRITE mat three times (3 trials), where the first one was a practice. After the results metrics like stance time, step length, step time, Heel to heel base of support were analysed. They concluded that the PD subjects attain a significantly lower FAP score when ambulating at their preferred rate and demonstrate shorter step length and a longer step time than the age matched non-impaired group during both preferred and fast velocities of walking. Their results indicated that the GaitRITE system can be useful in detecting footfall patterns and selected time and distance measurements of persons with early stage Parkinson's disease. Also, the FAP score discriminates between the PD population and the non-impaired controls when walking at preferred rate.



Figure 2.1: GaitRITE System

Another laboratory system to measure physical capability are Force Plates, used to measure balance and body sway and, recently, devices like Kinesia, an integration of gyroscopes and accelerometers in a compact patient-worn device to measure tremors. In a study [11] 60 PD subjects performed the tremor subset of the UPDRS upper extremity motor exam including rest, postural and kinetic tremor while wearing Kinesia.

Quantitative kinematic features were processed and highly correlated to clinician scores for rest tremor, postural tremor, and kinetic tremor. The quantitative features were used to develop a mathematical model that predicted tremor severity scores for new data with low errors.

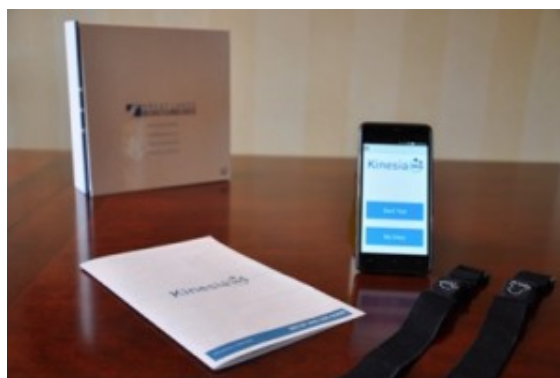


Figure 2.2: Kinesia System

Another curious example of non-wearable device to measure physical capability is the [4] research where he introduced to a clinical approach a gaming device. In this study, the purpose was to validate the Nintendo Wii Balance Board (WBB) to assessment of standing balance. The WBB is defended as being an inexpensive, portable and widely available device. For the validity of this device they made a comparison between the WBB and the known ‘gold standard’, the laboratory force platform (FP).

The WBB and the laboratory FP have similar characteristics, the WBB contains four transducers that are used to convert the pressure into data. The data will be analysed afterwards and used to assess the force distribution and the resultant movements in COP. This system as already been used in rehabilitation programs of neurological patients with balance issues.

The WBB is mass-marketed and portable, and can be obtained for a fraction of the cost of the laboratory FP. These characteristics are referenced as the reason for this device to belong to the clinician’s testing battery if it can be shown to produce reliable and valid data and results. Therefore, they made this study to compare the COP of this device (WBB) with the gold-standard Force Plates in a variety of balance tests.

In this study thirty subjects were recruited, all of them were previously checked and verified to assure they do not have any lower limb pathology by performing a combination of single and double leg standing balance test with and without their eyes open.

Four standing balance tasks were performed by the subjects, these balance tests were: single limb standing with eyes closed (EC), single limb standing with eyes open (EO), double limb standing with EC and feet together and double limb standing with EO and feet a comfortable distance apart.

After the data analysis where they filtered the data of both devices with an 8th order Butterworth filter with a 12Hz low pass cut-off frequency they got the outcome they needed to assess the balance, the COP path length.

For the statistics, they examined the agreement between the two systems with a Bland-Altman plot for the COP path length, metrics as intraclass correlation coefficients, standard error of measurement and minimum detectable change were also calculated to evaluate the validity and reliability between the WBB and the FP.

After the results analysis both devices showed an excellent COP path length, every test was excellent and reached values of ICC between 0.77 and 0.89 except the double limb standing with EO and feet apart in the WBB, this has led to the conclusion that WBB is a valid tool for assessing standing balance. The examination of the BAP plots showed no relationship between the difference and the mean in any protocols which represents the reliability of this system in comparison with the FP, so for a cheaper price an average clinician can access this system in order to measure and assess balance in PD patients.



Figure 2.3: Wii balance board

2.2.2 Wearable devices

The economic and size problems led to an increased demand for cheaper and smaller devices for the measurement of physical capacity capable of accurately and consistently quantifying human movement for the various tests described above [19, 22, 26]. For instance, in [19], they applied a set of metrics to understand which of them are the best to make an analysis of the postural control/ body sway. they compared the accelerometer validity with the force-plate measures and, after this, tested an automatic clinical system (ISway).

For these studies they chose 2 populations, the first one was with 25 subjects, 13 untreated and 12 with controlled Parkinson disease. For the second study, they were 34 halves controlled and half untreated patients. To all of the subjects they placed a BWM (Body Worn Monitor) MTX Xsens (49A33G15 +/- 1.7 range), at the Lower Back of their

torso (L5) and they used the force plates to make the comparisons needed between both technologies. The tests realised were just balance tests where each of them stand in the force-plates for 2 minutes with their eyes open (3 trials), and used the accelerometer for 30s and after a 30 minutes rest they did it again (3 more trials). In this study, they used MATLAB to visualise the data obtained and they filtered the signal (collected with 50Hz frequency) with a 3.5Hz cut-off, zero-phase, low-pass Butterworth filter to eliminate the 4-7Hz PD tremor symptom.

Another example of balance evaluation using an accelerometer was in the [22] research, where they investigated if they could differentiate between young and elderly healthy subjects looking at the body sway during quiet standing, they used an accelerometer (Logger Technology) positioned in the L3 with a fixation belt during 2 Samples (36 community-dwelling (60-79) elderly and 50 young students (20-41)). The tests they realised were just postural control (balance) with some variations (surface, feet distance and eyes open/closed). After they measured the body sway of the subjects they applied some algorithms like the correction of Medio-Lateral axis, RMS of the Ante-Posterior(AP) and Media-Lateral(ML) axis and used a quadratic curve and a moving average estimation to filter some irregularities. Thus, with these algorithms they conclude that with the unadjusted curve there was a large variability so it was not significant to the study, but after the horizontal transform the variations were much smaller and consistently high significant mean differences appeared. However, Low and Medium frequencies trend (quadratic and moving average filters) had no additional effect on the results.

After all, they defend that the variability of some results may have happened due to some problems, as the gravity component, slow body sway and accelerations representing responses to balance control challenges.

Beyond balance, TUG exercise was also target of some research as the study [26] that focused on obtaining metrics from the TUG test using an accelerometer and show subtle differences in the test performance that can't be quantified/observed by the actual way of measuring TUG (using a stopwatch-based approximation), in this study were assessed 17 patients (2 woman) with PD and 15 healthy subjects, they were asked to wear the Mobi8 system, a "mini-bag" that contains an accelerometer (Analog Devices ADXL330), the ACC was placed between the L3 and L5 vertebrae, measuring the 3 axis, AP-ML and Vertical and the data was later processed using custom Matlab software. In this paper after the TUG protocol they apply the [21] calibration algorithm to obtain the horizontal-vertical coordinate system, obtaining an M lookalike wave in which they can differentiate all the TUG phases. They separate the Sit-Stand (Si-S) from walk from Stand-Sit (St-Si), and in the each of the PT steps they divide the transitions in 2 equal parts (duration). After this they start computing the metrics: Range, Jerk, Delta Jerk, Duration, Median, Acceleration SD.

At the end of this study they concluded that the accelerometer differentiated better

the TUG duration between the PD group and the control group than the stopwatch- based approximation. The Si-St phase didn't show major differences between PD group and Control group, and they thought this happened due to the fact that the patients were tested in the ON phase of the medication. It was possible to see that the first half of the Si-St was longer for the PD than for the control group as expected. In the St-Si they could differentiate again both groups looking at the Range and Jerk of the first half of the exercise. In conclusion, they argue that the use of an ACC will help measuring TUG metrics that cannot be visualised/obtained by simple visual analysis (i.e., eye).

One of the problem of the accelerometers are the positioning of the device, and for this problem some studies were made to find the best locations to obtain physical data. For example in [6] research, the objectives were to examine the impact on gait characteristics depending on variation of accelerometer location (chest and waist compared to L5) during preferred and fast gaits speeds in a group of younger (20-40 years) and older (50-70) adults. They also investigated adjusted versions of accelerometer algorithms to better inform their deployment due to change in device location.

Each participant wore three tri-axial accelerometer (Axivity AX3) using double sided tape and Hypafix, the locations of each accelerometer were at lower back (L5 vertebrae), on the sternum (chest) and laterally on the right hip (waist).



Figure 2.4: Axivity AX3 with wrist band.

During the tests, the participants wore their usual footwear and walked at self- selected and fast-speed over a 25m route continuously for 2m.

After the testing phase, they applied the algorithms to the data collected from each subject, after applying the accelerometer algorithms they were able to demonstrate the following metrics: Step time and Step length.

For the data analysis were calculated the variability and asymmetry values for each accelerometer data, the variability was the standard deviation of all steps and asymmetry was the absolute difference between left and right steps.

After this evaluation, the data was analysed and they found out that the device location, walking speed and age influenced the evaluation of gait characteristics: chest results showed better agreement than those evaluated from the waist. Walking speed did not have impact on the evaluation of mean gait characteristics. Asymmetry and variability showed better agreement at fast speed. Age had an impact on all characteristics and better results were found for Young Agents compared to the Older ones. In conclusion while mean spatiotemporal gait characteristics were robustly quantified irrespectively of device location, walking speed and age group, this was not true for variability and asymmetry characteristics.

The AxivityAX3 accelerometer described above was validated in the [13] study referenced in the first part of this chapter, but it was not fully described and it was not explicit the outcomes of the study. Therefore, with those exercises Godfrey applied a set of algorithms with the intention of standardizing some of the algorithms to the respective exercise. First, for the balance, they applied two algorithms: Jerk and RMS, both algorithms were only applied to the Medio-Lateral axis:

$$Jerk = \frac{1}{2} \int_0^t \left(\frac{da_m}{dt} \right)^2 \quad (2.1)$$

$$Root\ Mean\ Square = \sqrt{\frac{1}{n} (a_{M1}^2 + \dots + a_{Mn}^2)} \quad (2.2)$$

For the second test, the (locomotion, endurance) they used a Gaussian continuous wavelet transform to estimate the Initial contact (IC) and Final contact (FC) so they can estimate the total time to complete the 4m. Additionally they calculated different gait characteristics using the IC and FC values (e.g., Step, Stride, Stance).

The third algorithm was also used for locomotion and endurance, they applied the inverted pendulum model to estimate the step length which will be resumed below. After these two estimations, they combined both values and generated values for mean step and velocity.

To obtain the metrics of the TUG exercise, they primarily estimate the time of the Sit-Stand transition from a discrete wavelet transform [1]. The total time of the transitions was derived from the first sit-stand to the last stand-sit.

With this study they concluded that the best metrics to measure balance were clearly Jerk and RMS. For the locomotion test their algorithms estimated a longer time than the measured one. The endurance overestimated the distance walked but estimated different metrics like step stride, step length, swing time etc. For the Sit-Stand transitions, the BWM showed shorted durations and in the last test (TUG) the estimated times were sim-

ilar to the measured ones. These facts led to a conclusion that a body worn monitor such as the AxivityAX3 is suitable to objectively measure and quantify physical capability in the tests they presented.

As referenced above, in this [28] study, they used four implementations of the Inverted Pendulum model of human walking to estimate spatiotemporal gait parameters.

In this study 20 older adults (independent-living) were asked to attend at 2 test sessions on different days. The subjects walked along 30m SL (straight line) path, 12 trials of 30m at self-selected speed were performed, 2x2 trials at preferred speed, then 2 trials at respectively fast, preferred and slow gait velocity. Finally, 2 trials at preferred speed where completed while simultaneously performing an audible version of the Stroop task. Subjects wore a DynaPort, McRoberts hybrid sensor, containing 3-axial accelerometers and gyroscopes, using a belt they entered the sensor on the lower back at the level of vertebrae L2-L4.

At data analysis, four estimators were applied were two used the simple inverted pendulum and the other two used one different algorithm denominated as two-stage inverted pendulum module. The difference between the first two estimators was that in the second they use an individual correction factor (F_i) contrary to the first estimator. In the first estimator, they used a default value of 1.25 for the F_i component, and the following formula to estimate step length:

$$\text{Step length} = F_i * 2\sqrt{2lh - h^2} \quad (2.3)$$

Where (h) was vertical position amplitude change, and (l) leg length. The vertical amplitude was obtained as the difference of the highest minus the minimum position of the centre of mass in the total step cycle. The center of mass was obtained with a double integration of the vertical lower-trunk acceleration.

The difference between the third and fourth estimators where they applied the two-phase inverted pendulum defended by [15], where they changed one constant for a variable value that differs from a patient to each other.

After this research, they concluded that the IP-model was highly reliable and demonstrated a good to high agreement in the estimation of the mean step length for indoor, straight line walking. The second and fourth IP models that used the adjusts to each patient lead to a better approximation of reference step length. However, they defended that they are harder to implement due to what they require in the algorithm.

Therefore, it is indicated that the generic algorithms with the constant values should be enough to evaluate the actual step length differences intra-individuals.

The algorithm discussion and validation is not only an active subject in obtaining gait characteristics but also in obtaining values for the posture transitions and balance. As referenced above, this [1] study, where they developed a wavelet based algorithm for detecting and calculating the durations of Stand-Sit and Sit-Stand PT (posture transitions)

from the SVM (signal vector magnitude) of the measured acceleration signal of the body worn accelerometer. This accelerometer was Part of Alive Heart Monitor marketed by Alive Technologies and was placed in the right hip with a fixation belt. The population of this study were 5 healthy and 5 elderly geriatric subjects divided in 2 samples.

Both groups made Sit-To-Stand and Stand-To-Sit tests, to calculate the differences needed to obtain the SVM of all three-axis measured of each subject and apply a 5th order Meyer DWT (discrete wavelet transformation) filter (using the wave decomposition function provided by MATLAB).

The data analysis followed the following steps: Recognize a time window where the PT happened, reconstruction of the 5th order Meyer DWT approximation, find global minimum and maximum of the signal to classify the type of transition and lastly estimate the transition duration by multiplying by 2 the temporal difference between the max and min.

After this algorithm application, they were able to show all 4 stages of each type of transition, for example in Sit-Stand: Forward bending, Active raising, passive raising and downward setting. Thus, comparing the elderly subjects with the young subjects in terms of stand-to-sit the differences were meaningless but in the Sit-Stand test they got a significant difference. One last idea left in this paper was to use the amplitude of the wavelet to know if the Stand-Sit transition is voluntary/controlled or involuntary and could be considered as a “fall”, this could have led to a major difference between both groups.

A different approach to the postural transition time estimation was recently researched, in the [12] study, they presented a new algorithm to detect posture transitions, more accurately sit-stands and stand-sit transitions, denominated by VESPA. It was used 2 ways of measuring postural transitions with accelerometers where he choose 40 young healthy participants and 40 older healthy participants who used 2 accelerometers AxivityAX3, one in the lower back (L5) and another one in the chest (sternum).

In this study, subjects were asked to complete Si-St and St-Si transitions while they were being filmed, they made 3x Si-St and 3x St-Si from 2 different chairs with similar height. The main idea was to measure the PT (Posture transition) duration and compare them with a filmed version of the exercise.

In this paper, they used 2 different algorithms 1 for each of the positions of the ACC, for the chest they used a Scalar product and vertical velocity estimation denominated by VESPA algorithm. For the lower back, they used the same algorithms as showed in the [1], with the signal vector magnitude and a discrete wavelet transform.

It turned out that the VESPA results were better in the estimation of the time than the Wavelet approximation. The problem that was pointed is that the L5 positions is less accurate in measuring accelerations/movement of the upper torso, which made the VESPA algorithm more accurate with detecting the transition in both young and older

subjects.

2.2.3 Discussion: Wearable vs Non-wearable devices

The wearable and non-wearable discussion is an active subject in this scientific field. As seen before the usage of wearable devices is increasing and that is probably be highly noticed in the future years. The use of a less intrusive device, smaller, cheaper and capable of obtaining the same metrics as the big, expensive and older technology-based devices is what is making this subject such an important matter nowadays.

However, this problem is not as simple as it seems to be, the standardization of the old devices is what keeps the skepticism of so many clinicians. Thus, currently there is a major research focused in standardizing algorithms, exercises and location of these small wearable devices, what will be achieved in the meantime and used in a near future.

One last problem with the integration of the wearable devices in the current medic appointments is the best device brand to choose. Due to its low production cost, many companies are selling these devices and most of them use black-box software.

This way of hiding the code carry a disadvantage for the scientific evolution, and that is the reason we selected AxivityAX3 as our accelerometer. AxivityAX3 is a cheaper accelerometer with an open-source code that let the consumer use all its resources and implement new ones that can later be published and used by other interested researchers[14].

2.3 Data-Driven: Supportive tools for clinicians

Data-driven consultation is an approach to the way doctor's appointments are guided. Data-driven consultation is an existing concept that came to solve the clinicians difficult to gather and understand patient data in the medical laboratory. The main objective of the data-driven consultation is to comprehend patients and obtaining and correlating different types of patient data, such as vital signs as defended in [17]. In this paper, Kim et al. decided to concretize a workshop to design a clinical interface integrated with data-driven consultation to help clinicians and patients and investigate the role of the developed software in situ.

In Kim's research, they introduced the necessity of this platform based on situational clinical constraints such as the lack of time that a clinician has disposable for a patient and the information overload that is collected during throughout the course of a medical appointment by the clinician. However, many hospitals are looking for an integration of data-driven consultation in their consultations.

It is critical to obtain information on patients' everyday specifically if they suffer of some chronic disease and from overweight, this is important for clinicians' due to the requirement of precise diagnoses and suitable treatment. The data-driven consultation aims to solve problems like the verbal recall of daily habits that the patients and clinicians

are used to do in the past, which forced doctors to make estimations. The data-driven consultation will assist clinicians in a fast and deeper understanding of patient' behaviors and feelings compared to the previous methods.

It is important to emphasize that the integration of data-driven consultation, where clinicians use self-logged data did not exist until recently. Thus, in this paper, they focused in helping clinicians understanding patients quickly by creating an interface that simplifies the check-up appointments. However, due to the lack of research on the role of actual clinical interfaces and the mode this interface should be designed, Kim used two research questions to be answered and used to complete the research, which were:

“ How should a clinician interface for data-driven consultation be designed?”.

“ How does the newly designed clinician interface help the integration of data-driven consultation with the current routine?”.

To answer the questions above, they led a user-centred study with a duration of 15 months to expedite the design process with 18 stakeholders, which they divided in five stages, the preliminary study, where they investigated the current workflow it integration with data-driven consultation. They identified four behavioural tasks executed by the clinicians: Check lab data of the Electronic Medical Record system (EMR), asking follow-up questions to the patients, writing comments on the EMR and prescribing and explaining medication.

After this stage, they proceed to the second one where they focused on the design goals which were split in three: Helping clinicians accessing data quickly, the facilitation of doctor-patient collaboration and discussion using the platform and prevent goals from being missed by designing an interface that records them.

The design workshop was the third stage of the research and the objective was to understand how the three different design goals were reflected in the clinician interface. It was discussed different types of data visualization and agreed that the best ways to assess data was using common formats such as line and bar graph formats. Many clinicians tried to divide the day into three stages: morning, afternoon and evening to be able to assess information in more detail.

In the fourth phase, the implementation, they created the platform and named it DataMD. The platform had a dark theme and they confirmed the six types of data that they need to show classified in two categories (primary and outcome data), primary contained activity, food and sleep and the outcome data contained stress, weight and blood pressure data. After this separation, they created areas for the holistic, primary and outcome data, the holistic data had the patients profile and a numerical summary of the average number of steps, for portion size and frequency of eating and sleeping. The primary data area contained the three areas described above and the same occurs to the outcome data area.

The last stage of the study was the field study where they investigated how clinicians interact with DataMD. This phase consisted in an observation of a total of 32 medical check-ups during a month. During this phase, each patient was provided with Misfit devices to log their steps and sleep data and also an app to help collecting the food, stress, weight and blood pressure. The DataMD led to a new workflow around the interface created by the clinicians reducing the behavioural tasks to three, clinicians at first read the interface as intended by the developers but after a period of time started to interpret data by themselves which led to a faster reading and understanding of the data. The DataMD also facilitated the communication and collaboration between the patient and the clinician and it doesn't show to reduce the number of eye contact made by both of the participants.

This study revealed that it is possible to integrate data-driven in the existing workflows. However, there are many restrictions remaining that must be surpassed not only with the interface design but also with the collaboration of experts in both areas, medical and HCI fields. For this research in particular it is important to keep in mind that the interface was a connection between patients and clinicians like a translator. Still, there are some risks involved in the use of this interface, like the data misinterpretation by the clinician. For future work Kim decided to emphasize the importance of study the patient side of the medical appointments, having in consideration that this paper was focused in the clinician view, such as modifying the goals and platform flexibility.

2.4 Discussion

With the introductory literature review it is known that the data-driven platform is a mechanism that will give the necessary support to the control of Parkinson's that the clinicians do not have in the current days. The proposed platform will enable the clinicians to follow and deal in a more dynamic and personalized way with patients with a disease as diverse as the symptoms such as Parkinson's.

To achieve the goal with this project we will use an AxivityAX3 accelerometer to obtain patient data and then be analysed and presented on the platform. The choice of using this accelerometer was made based on previous studies and the tendency to use small, cheap and less intrusive technologic devices to measure human behaviour.

Due to the huge demand in developing algorithms in the field of accelerometry in order to be able to measure the human physical capacity, it is difficult in this project to find the perfect algorithms, and the ones that will be implemented are the ones closest to being standardized in order to give conclusive and reliable data to clinicians.

Chapter 3

Understand the role of technology in clinical assessment

Although my major concern is with people affected with Parkinson's, I considered that the best way to help these patients is improving the tools that the ones closest to them and who are technically formed to work with them: the clinicians and physiotherapists.

This study is mainly focused on clinicians due to the lack of knowledge of healthy aging metrics and medical assessments. Thus, working together with CNS (Centro Neurológico Sénior / Senior Neurological Center) we were able to reach a network of professionals, receiving an amount of positive information, but mostly we got the clinical knowledge needed to understand the clinician requirements to work with patients with this neurodegenerative disease.

We chose to use an iterative co-design methodology, there was a close relationship between us and clinicians that work with patients with Parkinson's. With these conditions we aimed to increase incrementally our system, using the feedback and usability metrics to prove what is right and wrong and leading to a refinement of the system in the next iteration. The constant feedback and observation of the system workflow and capabilities led to a lower risk level of the project.

3.1 Observations

To identify the needs of our end users, multiple observation sessions and focus groups were made, observation and focus group sessions that are extended to the current days. Mostly between November 2017 and February 2018 a set of clinical observations, films and multiple interviews were organized with the objective of improving the knowledge of the actions performed during a Parkinson clinical appointment and how the traditional and current medicines treats the patients.

During this period, we discussed the current protocol used to evaluate the patients at the clinic and after the previous focus group, we obtained an idea of this protocol at the end of it.

Divided in two major groups which were the physical and the interview part, the protocol interview part was the one composed by the subjective scales, scales used to evaluate subjectively the cognitive and physical status of the patient.

The second group of the protocol is the one that is divided in 5 stages which were the 5 different exercises that a patient must perform during an appointment:

- **Timed Up And Go (TUG)** : This exercise starts when the clinician indicates and the patient has to lift up from a chair without arm support and start walking with the left leg at normal speed for three meters until the mark that is on the floor and thereafter circumvent it for the left side, turning back and keep walking to the chair, sitting and leaning back. The exercise ends when the back hits the chair. Both base evaluation and reevaluation consist in 3 trials with dual-task and another three without it, where the duration of each one are written down in seconds, with the three trials from both tasks, a mean value is calculated to be used as a risk of falling evaluation metric.
- **Five times sit to stand (S2S)** : Sitting in a chair with arms crossed over the chest, the test consists in multiple repetitions of standing -up and sitting down again, to complete one repetition the patient must touch with his back in the chair backrest. The test ends when standing-up after repeating the stand up, sit down cycle five times. The value used to measure the patients risk is the exercise duration as well as on the Tug and Walk exercises.
- **10 Meter Walk (Walk)** : This test consists in walking at a comfortable speed between two spots on the ground marked with lines.
- **Balance test battery (Minibest)** : This test is actually a battery of 13 tests that evaluate different parts of the patient's balance. Each test is classified as "Normal", "Moderate" or "Severe" depending on the patient performance and effort giving a final classification and comparing that classification with an existent validated value evaluate if the patient has or not risk of falling.
- **2 Minutes Step (Step)** : Measuring some health values at the beginning and at the end this exercise corresponds to the longer single task of the protocol, the patient must perform step during 2 minutes and the number of repetitions accomplished will be used to the evaluation as well as the health metrics measured.
- **360° Rotation (Rotation)** : This exercise was added after some observations and it was added after some time discussing it with clinicians that insist that its a decent indicator of freezing. Thus, the patient must perform 360° turns for each side and the clinician must stay focused and searching for signs of movement freezing. The number of freezes and the time consumed to the execution are the metrics obtained from this task.

During our observations the following story occurred, this is a description of how a clinical appointment looks like and the patient name will be mocked due to identity protection, from now on "João" is the name used to identify the patient in question.

We started by dressing a lab coat and preparing our positions and observers trying to position ourselves in a way so we do not interrupt or disturb the appointment execution, during this time the clinician prepared the AxivityAX3 to record the data and left it ready to be placed in the patient trunk and wrist.

After the preparations we were ready to mark the data and taking notes, Mr João entered the room and went to the designed chair guided by a clinician. I prepared the laboratory protocol that we were about to see being performed by João and the consultation started.

At first, the clinician was asking simple questions about how he felt physical and psychological, the answers of those questions were collected and transformed into data expressed in numbers on validated scales used to measure physical and mental health. Right after this 20m interview, it was asked to Mr.João wear an elastic belt that contained the accelerometer, he also wore another accelerometer at the wrist so we can see the fluctuations of the body. At the moment that the physical tests were about to start, the clinician explained each one of them and then choosing to start by the TUG.

At TUG, Mr.João performed 6 trials, where 3 were without an additional task and the other 3 were with another task that was counting from 30 to 0, 3 by 3. This exercise was successfully done and the duration's of each trial were collected into the sheet that the health professional had in hands. After TUG Mr.João rested for a while, while getting the instructions to the second exercise which was the Sit-To-Stand that consisted in the 5 times Sit-Stand and Stand-Sit repetition performed twice, this activity was completed with no major effort by the patient.

Now at the Walk exercise, the 3 first trials were performed without interruptions and the methodology observed was: the clinician follows the patient counting its steps and managing the chronometer in one hand while using the other one to assist the patient if needed, after the first 3 trials were completed the clinician wrote the data in the sheet (number of steps and execution time) of each trial.

Meantime the subsequent three trials were performed the same way than before but way slower due to the dual task and it was obvious the fluctuations in the patients body while we was walking and counting at the same time, this led to a major attention of the clinician to the risk of fall of the patient.

For now we were reaching the forth exercise of the assessment protocol and the clinician was began by explaining once more that the forth stage was the "minibest exercise battery, used to classify the balance of the patient and verify the fluctuations of the body" which led to a better understanding of the objectives traced for each exercise that was being performed.

The first exercise, "Sit-To-Stand (balance)" was "jumped" and instantly classified due to the previous performance of the Sit-To-Stand major activity in second place during this appointment. The following exercises were performed without major concerns or problems, starting from "Rise to Toes" and only having problems as of the "Incline eyes closed" where the patient lost his balance and the clinician was forced to grab him by the waist and shoulder so he could regain his balance and stand still again.

Approximately to the fifty minutes of duration we reached the two minutes step activity which was the last one from the protocol physical part, here the clinician brought a step board close to the patient and explained how the exercise must be performed, after a brief period of questions about how the patient felt, he assumed that was fatigued and considered that some exercises were harder to perform due to its declining health state lately.

Afterwards the initial measures of Oxygen saturation, heartbeat and pain value were gathered. Followed by the preparation of the chronometer to count the two minutes needed. At the start of the countdown the steps were fast and vigorous and it was not necessary to give any major support but as we passed the 1 minute mark the exercise became slower and less coordinated which causes the clinician to move closer and stay alert in case of any major risk of fall.

Upon the end of the 2 minutes, the three measures were made again and this time it was obvious an increased value of his heartbeat and pain in the Borg scale. Lastly, a few questions were made about his own opinion of the performance and effort during the protocol's execution, these were answered and confirmed the points taken through our observation.

3.2 System Requirements

Defining the system requirements involves considering which tools and other software frameworks are being used nowadays by our stakeholders, i.e., clinicians, and with this mindset focusing in producing a system that goes according to the needs of those stakeholders.

Simplifying the clinician work and having as a purpose increasing the interaction time

between patient - clinician decreasing the multitasking that each stakeholder has to do during an evaluation goes according to the objectives of this thesis and is a major factor to the success of it. Thus, through interviews and observation sessions previously detailed some conclusions were drawn:

- It is hard to include new technologies in the traditional appointment methodology;
- The performance of the Parkinson's test battery needs as much attention to the patient as the clinician can give because of the imminent risk of fall that these kind of disease causes;
- Clinicians are used to work reports following a template to easily look and access the data and improve the efficiency of the laboratory appointments;
- The insertion of new systems leads to a lot of time consumed due to the need to learn each functionality of the system;
- Some systems and equipment are already validated and used to help clinicians measuring the evolution of their patients Parkinson's;
- Patients data must be protected so that only his medical entity employees can access it.

3.2.1 Functional Requirements

Having account these conclusions, as functional requirements, DataPark should:

- Allow the protocol change of the clinical appointment in a case of any patient necessity or impossibility;
- Guarantee that the data collected is sufficient to measure and provide enough information to be used in the assessment and evaluation.
- Provide enough usability in the android application during the laboratory protocol to make sure the clinicians feel as they can change, revert and choose which exercise they want to evaluate at each time.
- Not only the exercises measures, the clinical observations are also a major interest to collect.
- Provide an account for each clinician, ensuring that patients' data are only accessible by the entity responsible for them;
- Provide mechanisms to navigate through patients' previous consultations;
- Allow a simple and fast process of patient creation;

3.2.2 Non-Functional Requirements

Relatively to non-functional requirements, the main concerns are:

- Usability – Since end users may not be familiar with new technologies, the system design must be minimalist and the use of the system must be intuitive;
- Performance – Once internet conditions may vary from place to place the system must have a short response and data transmission time;
- Availability – The system must always be available, so as not to interfere with the psychologist sessions calendar;
- Privacy – User data must be protected;
- Maintainability and Extensibility – Since this is only the first version of the system, it must be ready to meet new requirements or correct existing problems;
- Portability – The system must run in perfect conditions independently of the operative system, browser or device type;
- Documentation – Provide user guides, on-line help or quick-reference guides.

3.3 Use Case Scenario

From all these observations and requirements a base use case scenario was elaborated and agreed as the most common assessment performed by clinicians:

A patient goes to an appointment and the clinician pretends to evaluate which is his current state, first of all the amount of sensors desired to be used must have been previously charged and cleaned from prior appointments. Meanwhile, one accelerometer must be placed atleast at the Lower back (L5 vertebrae), other locations can also be measured but this is the one from where more reliable data is extracted.

Meanwhile, the clinician advances to the evaluation of the patient using a battery of physical tests composed of the previously described, where you will have to keep measurable data regarding the durations, scales and classifications of the exercises performed.

From the data obtained during the consultation it is possible for the clinician to obtain a report that synthesizes all information pertaining to the patient who has been evaluated. Information like the energy used during the performance or metrics from each activity are later used for discussion, evaluation of the patient's disease progression and to be analyzed in order to administrate the correct amount of medication to the patient.

3.4 Clinical support system

To simplify clinicians tasks, as we see in the scenario described above, it was decided that it would be created a set of tools to facilitate the way consultations are performed in clinical context.

We can list the interactions in order of need during a clinical evaluation:

Clinicians evaluating a patient require an accelerometer and a location to mark exercise durations and their ratings. Thus, we will use a low-cost accelerometer and a mobile application that incorporates the scales required for filling and a timer to assist clinicians during the performance of the evaluations.

After the evaluation, the integration of the signals obtained by the sensor and the data collected by the mobile phone will be done through a web application whose purpose is to maintain a history of evaluations of each patient and generate reports summarizing each appointment in order to simplify the evaluations of the patients and remove the need to resort to the traditional method of writing the data on paper.

Chapter 4

Implementation

The prior chapter and its discriminated interviews, focus group and discussions allowed us to identify the requirements that had to be met to create an useful tool that supports the clinicians treating and monitoring people with Parkinson's. DataPark is the system we developed to satisfy these requirements and, being used by clinicians, a tool that simplifies the current methods to a new way of measuring and monitoring Parkinson's, either at the clinical or free-living contexts. The laboratory context is the focus of my implementation along with the way how the clinician and the patient interact during this period.

Technically, DataPark focus on storing, processing, and delivering the data obtained from people with Parkinson's, generating reports which are used to evaluate and monitor the patient in question. In addition it is possible to change the clinical report and choose which data is going to be presented before printing it. Furthermore, DataPark is used combined with DataPark Mobile in the laboratory context, a mobile app that helps and guides the clinician through the laboratory appointment decreasing the amount of props needed to be held in hand and tacking track by the clinician during the consultation.

This chapter describes the implementation in a software engineering perspective of a solution to the now known requirements by the clinicians, culminating in a platform that can be used by any clinician that treats patients with Parkinson's, being able to be accessed by any computer via web browser.

DataPark is implemented using a set of programming languages, Java, Python, JavaScript, JQuery, CSS and HTML5 are the languages responsible by providing the best functionality and workflow of our platform. DataPark Mobile is a mobile app for android which was developed to be used at the same time as our platform programmed which I implemented using Android (Java) in Android Studio.

4.1 System Design

DataPark involves a variety of frameworks and workflows to improve the experience that the clinicians have interacting with our system. Starting with the input data, as it is ex-

plained before we focused on the data gathering by the Axivity AX3 accelerometer which already has a simple GUI to extract the data obtained during a consultation into a .csv file to be later evaluated and transformed into readable information and data to the clinicians.

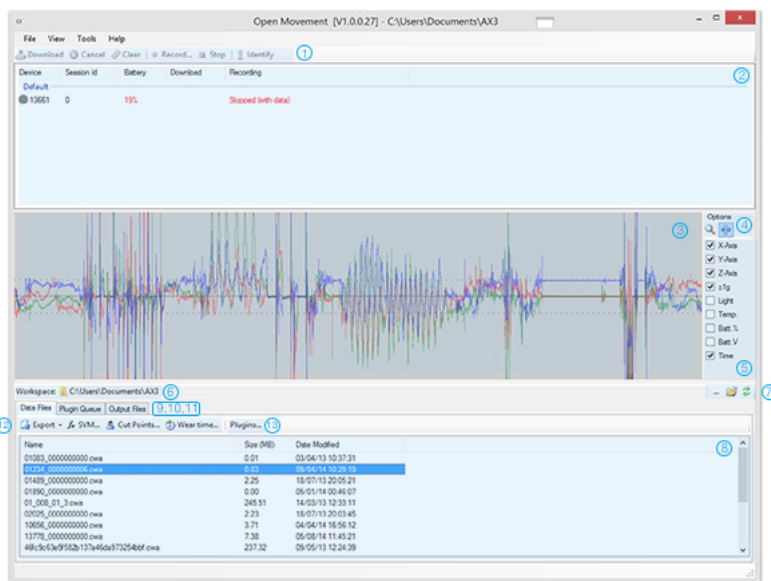


Figure 4.1: Axivity AX3 Graphic User Interface

However the usability of this technology by stakeholders that are not commonly in contact with software is questionable which led us to our own implementation of the data gathering from the AX3. Instead of interacting with this system to extract the data and then with our system to analyze it, I included the data transformation from .cwa to .csv in our system, the clinicians just needs to obtain the raw binary file from the accelerometer(.cwa) and upload it into our platform.

4.1.1 Software Architecture

Datapark architecture can be abstracted into 4 major modules as shown in Figure 4.2.

- Accelerometer - The accelerometer is placed in the patient that will be assessed. At the end of the evaluation the accelerometer is removed from the patient and its data is uploaded to the system via web app, being stored in the database.
- Mobile Application - The mobile application is used to guide the physiotherapist during the physical evaluation, at the end of the evaluation the data collected from the mobile app is stored into the database.
- Web Service - Containing the modules to store information (database) and to process it (signal processing server) this module is the center of the computation. When a clinician requests a report the web server is responsible for generate it integrating mobile and accelerometer data.

- Web Application - This last module is where the interaction between clinicians and the reports is made, a clinician can upload accelerometer data and request/view reports.

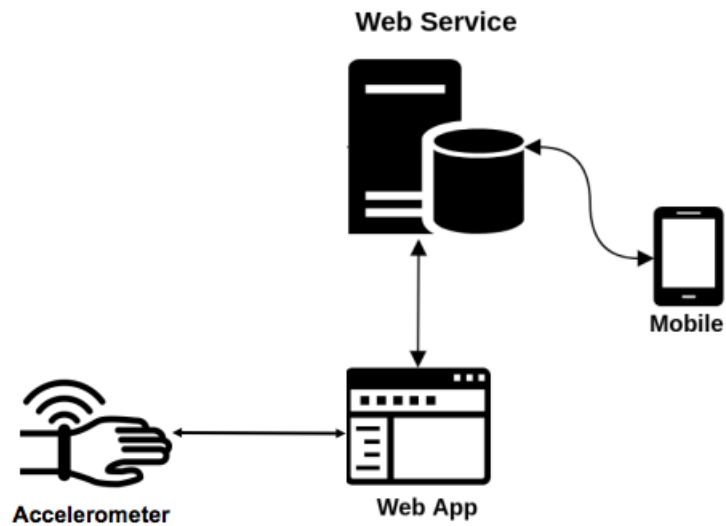


Figure 4.2: DataPark Architecture.

This system allows clinicians to easily monitor, gather and store data from clinical appointments. From the gathering to the monitoring we confine the interactions into one single system.

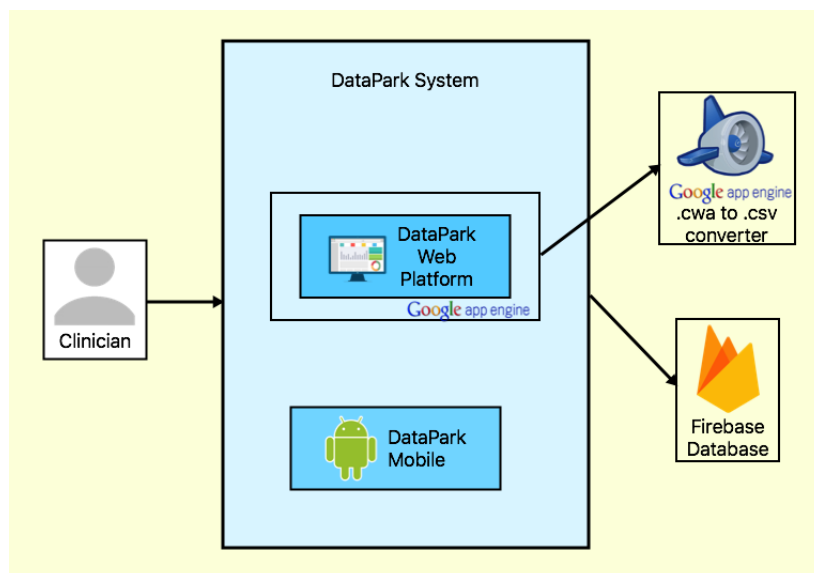


Figure 4.3: DataPark System.

- .cwa to .csv converter - As its name means, it is used to transform the Axivity AX3 signal natural file format (.cwa) into a readable file (.csv) and store it into our database associated with its patient.
- DataPark Web App - The web application is where all the operations of signal analysis are conducted and where each clinician can access and obtain the data from each patient previously evaluated.
- DataPark Mobile App - An android application used to guide the clinician and store patient information during the laboratory clinical evaluation, being soon after stored in the database and formatted to be expressed in clinical reports.
- Firebase Database - Database used to store the patients from each medical entity, their evaluations and their extracted signals from the Axivity AX3.

An example of interactions between all the parts of the system can be seen in the Figure 4.4, where we can see all the workflow from the registration made by the clinician to the report providing from the system.

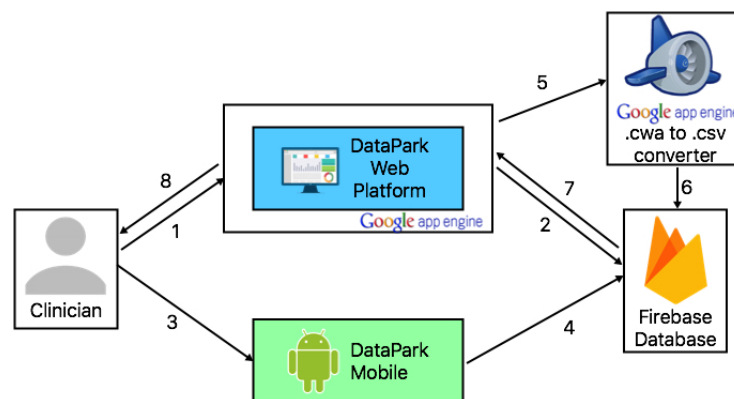


Figure 4.4: DataPark Use Case.

1. Interaction between the clinician and the web app, patient creation and edit, clinical appointment creation and report request.
2. Data saving and retrieving, storing new patients in the database and obtaining previously saved signals to generate reports respectively, also used to authenticate users and institutions.
3. Interaction between the clinician and android application, consultation walk-through using the app as support and data saving place for the information gathered during the clinical evaluation.

4. Connection between android and database, used to save a new laboratory evaluation for a specific patient.
5. Connecting element between base web app and another service which is used to compute the signals obtained from the Axivity AX3 and transform it into .csv files ready to be analyzed.
6. Link between the .cwa converter and the database, where the processed files are stored and later retrieved by web app requests.
7. Data retrieving from the system, patients, reports, signals and authentication requests.
8. System response to the current user (clinician), report response / report printing.

4.1.2 Data Model

It was decided to adopt Google's Firebase¹ database to store our data, this decision was based on Firebase being already a familiar database that could easily integrate data between an Android application and a web service. Moreover, the features provided by this Google's application are enough for the needs of DataPark System. Encompassing authentication, data storage (messages and files) and security.

Google Firebase is a Cloud Hosted NoSQL database that easily integrates multiple languages, for the android system I used the Realtime Database and Authentication services. Implementing the firebase in our web app was not as easy due to the nonexistence of libraries between Python 2.7 and Google's Firebase.

We implemented the communication between the server and the database using their REST API. For the web service it was required to use both authentication and realtime database, but also storage services so we can store bigger files.

When it comes to define the database structure we divided the Patients information in terms of Laboratory Reports, Android Reports and Wild Reports separately from the common information for each patient like age, birth, weight and height.

Due to the characteristics of my NoSQL database, more exactly because of the high number of relationships between entities, it would be bewildering for anyone reading it, so a small schema of the database will be presented and the relationships between that small portion will gonna be explained.

Patients and Appointments

The figure 4.6 represents what a Patient is in our database, basically a patient is a list of android reports that represent the data collected via Android during a consultation, Lab-

¹<https://firebase.google.com/>

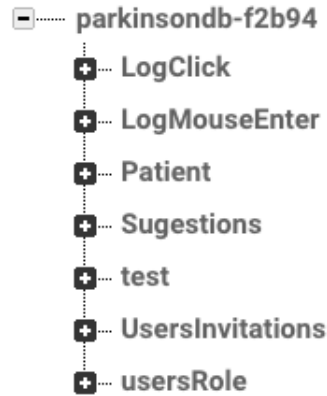


Figure 4.5: DataPark Database.

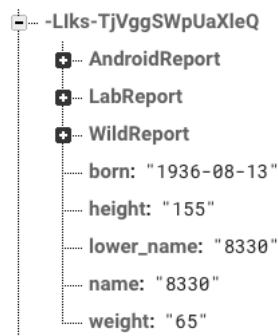


Figure 4.6: Patient stored in the database.

oratory reports that are the junction of both android report and the AX3 signal collected during the execution of the same evaluation, treated thereafter. Wild reports are the other feature of DataPark which will not be discussed because it was not implemented by me.

It is important to understand that a Laboratory Report must be connected to one Android Report, this is made by the clinician when he creates a new laboratory report for a patient and updates a new signal, indicating which Android Report corresponds to the current updated data. At this moment clinicians can use the same Android Report to many signals but each one of the Ax3 signals can only be connected to one Android.

Apart from the list of reports that each patient represents, to provide reliable data my algorithms use basic information about the patient, just like the entries we see above, age that its calculated based on the birthday, height and weight that are inserted by the clinician. All of the patients are differentiated using a code which is called "name" in the database. Inside our database each patient also has an unique id which is used to differentiate them internally in case of similar codes are being used.

Android Report

Android reports are the ones that usually store the duration, and starting times from each exercise performed. Each android report of each patient is identified a unique ID and has a map structure to represent each of the exercises independently, I have chosen to separate them for reasons explained in the previous chapter and for simplicity in the management of each one.

Common Fields

Every exercise has an "aborted" flag that, as the name indicates, is used to verify if the exercise was or not performed by the patient, in case of being true, another field is filled, "abort_reason" which is the reason why the clinician interrupted this exercise as we can see at the figure 4.7. Otherwise the exercise was performed and the "aborted" flag is false, this means that the trials are completed and the exercise was marked as done. It also exists a field "observation" for every exercise which is used to store meaningful observations taken by the clinicians during the exercise performance.

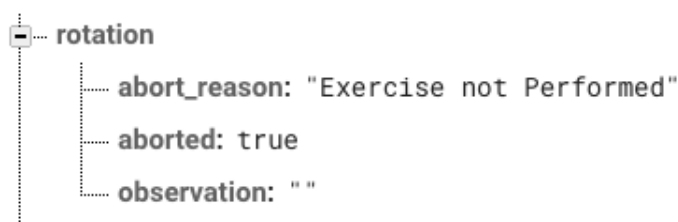


Figure 4.7: Aborted exercise example.

Specific Fields

Apart from containing the fields explained before, some exercises also contains the "default_dual_task" and "task_assistant" fields, expressing the dual task used to perform the exercises that evaluate the patient's throughput with multitasking and the which task assistant is required to the execution of this exercise (if needed), respectively.

In figure 4.8 we can see an example of the timed up and go exercise stored at the database, this was not aborted and, therefore, it contains the data from each trial . The fields that were not mentioned yet are the six tasks used to evaluate tug where "npt" is used to reference "normal_pace_tug" and "dt" to "dual_task_tug", the first, second and third of each one indicate which trial is.

Consequently at this figure we can see the three trials of both exercises (with and without dual task) and what is stored inside each trial."startTimestamp" is a Long value that represents the start time of the task execution in milliseconds, "duration" is also a Long value that represents the duration of the trial in milliseconds.

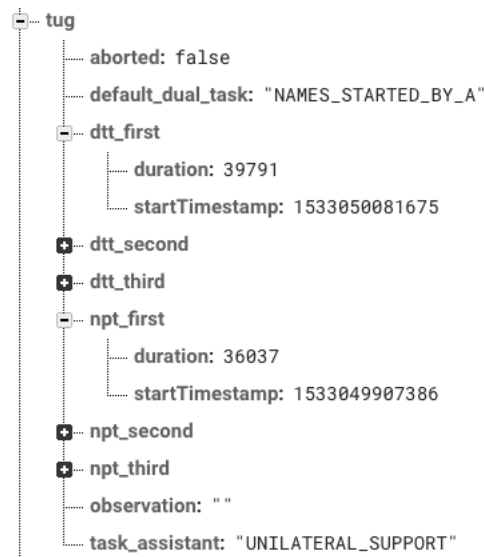


Figure 4.8: Timed up and go values stored on the database.

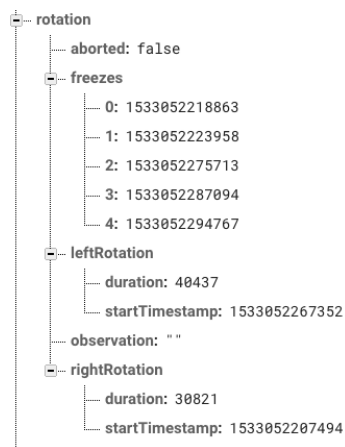


Figure 4.9: Rotation fields in database.

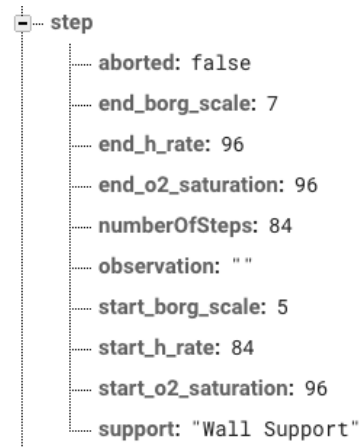


Figure 4.10: Step fields in database.

Represented at the figure 4.9 and figure 4.10 are two more exercises that have their own specific fields. Thus, step exercise introduce eight new fields to our database which are:

1. start_h_rate & end_h_rate - Two Double values that represent the heart-rate at the start and at the end of the exercise.
2. start_borg_scale & end_borg_scale - Two Double values that represent the numeric representation of the pain in terms of the Borg scale (from 0.5 to 10).
3. start_o2_saturation & end_o2_saturation - Two Double values that represent the oxygen saturation in the body before and after the execution.
4. numberOfSteps - Integer with the number of steps that were performed during the

exercise.

5. support - This field is used to specify which kinda support was needed (if it is the case) during the task performance.

This exercise is the only one that only had one trial, but also it is the only one that requires these measurements before and after its conclusion, that's why is so structurally different from the remaining. Not only step but also rotation has its own peculiarities, in this case Rotation has two trials, "leftRotation" and "rightRotation" that both have the same properties than every normal exercise trial but this exercise contains the field "freezes" which consists in a list of Long values that are the moment when the patient froze during the performance.

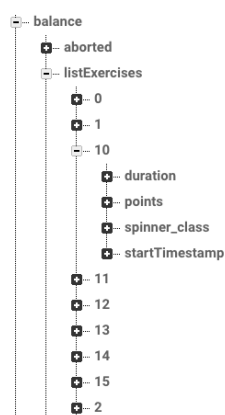
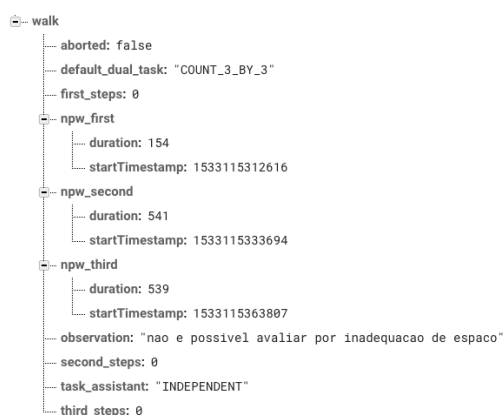


Figure 4.11: Walk fields in database. Figure 4.12: Balance battery test in database.

The Walk exercise is similar to the first one discussed, it has three trials and the major difference is that here for each trial also exists a field represented by an integer used to store how many steps were counted.

Alongside walk, in the figure 4.12 is an example of what is stored inside the balance exercise, beyond the common fields in this exercise exists a list with 16 entries correspondent to each task that must be performed to evaluate the balance of the patient. Each of these entries also have startTimestamp and duration as default but contain two more fields representing the evaluation given by the clinician to each task and the correspondent score represented by an integer.

Metadata

Over and above each of the exercises, every single android report also has basic data which is used to be identified and connected to the correct evaluation like "appointment-Conclusion" and "clinician" which are fields that represent respectively as they indicate, when was this android evaluation done and which clinician was evaluating. This is the way I connected a clinician to a patient when saving evaluations.

Lastly, there is a map called metadata as we can see at figure 4.13 used to represent data that is not considered exercises or identifier of this android report. Metadata is composed by:

1. affected - Represents which side of the body is mostly affected.
2. device_location - List of locations where Ax3 Axivity accelerometers are placed during this evaluation.
3. march_assistant - Which march assistant the current patient is using, if it is the case, otherwise is nothing.
4. height - Due to the time gap between evaluations, this data from the patient is asked every evaluation and is used to update its current common data.
5. weight - For the same reason as above this information is also required every evaluation.
6. age - In discussion with the clinicians they asked to insert also the age from the patient in case he is not yet created and this speeds up the process.

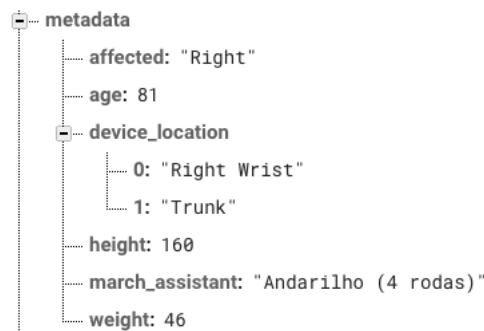


Figure 4.13: Metadata of an android report at the database.

Laboratory Report

Each laboratory report represents a saved instance of a AX3 signal obtained during a evaluation and connected to the Android app report that was made during the same evaluation. So during the same evaluation it is possible to have more than 1 laboratory report, because each report corresponds to only one signal, and during one evaluation a patient can use more than one accelerometer, the connection point between these are the "androidKey" field that connects them to the same spatial-temporal evaluation guided by the Datapark Mobile app.

For every laboratory report there is a structure that must be fulfilled, this structure is divided in 8 fields:

- age, weight and height : These three fields must always be present, they are the same as the android report if they are previously inserted via my android application.
- androidKey : Hashkey that indicates which android report is connected to this signal.
- devicePosition : Position of the device from where the signal was obtained and uploaded.
- fileId : Simplest identifier of this report.
- filename : Name of the .cwa file that contains the signal of this laboratory report.
- key : Own id used to simplify the search.

Users roles

To separate which user can see what it was necessary to create the "role" concept, where the users can be normal users and admin users. Normal users can log in to the web app, create patients, reports and see them, but to create a normal user there must exist an Admin user. Therefore, Admin users can invite, delete and change permissions of normal users, that's the way a new clinician is registered in our system, by invite from a user with superior permissions, an Admin.

4.2 System Implementation

To structure and provide the best usability possible to the clinicians with all the data that was previously showed required a lot of effort in terms of knowledge and adaptability to the frameworks used.

In this section will focus on the technologies that were used, the back-end work-flow to produce the required results and about the front-end technologies used to improve the user experience and usability of our platform and mobile application.

4.2.1 Used Technologies

Since there was no major economic fund to use in this thesis the only things that were more expensive were the Axivity Ax3 accelerometers which we bought from Newcastle's University HCI Group and the Google App Engine² cloud to host our web app in their servers. Therefore, no more services and technologies used in this thesis were bought, being said they are all open source and free.

²<https://cloud.google.com/appengine/>

Other factors apart from the cost are also important, as my knowledge level about the technologies that were used and their learning curve. Coming from a Software Engineering branch, my knowledge about Web development and Systems Information were also tested, bearing in mind that I did not have subjects that directly addressed these issues during my journey in college.

Back-End Technologies

In terms of back-end technologies this project is considerably rich, using Python and Java languages to the web app and activity signal transformation services, but also Google's firebase as database.

The Java language was used to create a .jar file that is running in a Google's App Engine server outside of our web app, and what it does is convert the .cwa files into .csv files as explained in the first section of this chapter.

The Python was used along with the Django³ framework. Django is a free and open-source web framework, written in Python, which follows the model-view-template architecture and simplifies the creation process of web services simplifying the security issues due to the protection against the most common attacks to web services and data encryption.

Apart from the framework itself, multiple python libraries were used to implement the objective algorithms faster and optimized, the most important libraries were:

- Scipy⁴ - SciPy is a Python-based library of open-source software for mathematics, science, and engineering. This library contains multiple packages, Pandas and Numpy are two of them used to provide easy-to-use data structures and data analysis tools for the Python programming language and multiple mathematical facilities like powerful N-dimensional array object operations, respectively.
- PyWavelets⁵ - PyWavelets is open source wavelet transform software for Python used to process the data from the AxivityAx3 .csv file.
- peakutils⁶ - This package provides utilities related to the detection of peaks on 1D data. Includes functions to estimate baselines, finding the indexes of peaks in the data. It was mostly used to detect peaks and its correspondent indexes in 1D data.
- firebase_admin⁷ - Admin Python SDK enables access to Firebase services from privileged environments (such as servers or cloud) in Python. It was used to be

³<https://www.djangoproject.com/>

⁴<https://www.scipy.org/>

⁵<https://pywavelets.readthedocs.io/en/latest/>

⁶<https://peakutils.readthedocs.io/en/latest/>

⁷<https://github.com/firebase/firebase-admin-python>

accessed as an admin from our server where we could test the insertion, deletion and edition of Patients and other fields of our database.

Front-End Technologies

The front end required a hand full of different technologies, the chosen ones were picked based on familiarity and previous knowledge. HTML5 is used to structure the web pages and presenting the page contents which are embellished and dynamic due to the use of CSS3 and JavaScript. The web pages are responsive and work in different screen sizes and devices using the Bootstrap⁸ front-end framework.

Javascript was used to the visual dinamism of the wep pages but also for data representation which is one of the core points of this thesis. D3.js⁹ and jQuery¹⁰ are used, respectively, to generate charts and grids representing the data and create Ajax requests simplifying the data loading from the server while filling and manipulating HTML elements.

With these battery of languages and technologies I tried to offer a responsive, adaptable and intuitive web app where the clinician can navigate and quickly achieve the intended operations always feeling confident and comfortable.

Mobile Application Technologies

The Android Application was made in Java using the Android Studio editor, I had the concern to make it run in every Android that runs Android 5 or superior. This application used some external packages for different objectives, Google's Firebase android package ecosystem was the most used because of the need to communicate with the database to save and fetch data.

To ensure the authentication and data transfer from the mobile app to the database two packages were imported:

```
implementation 'com.google.firebase:firebase-database:11.8.0'  
implementation 'com.google.firebase:firebase-auth:11.8.0'
```

Beyond the firebase's package, Glide¹¹ framework was used to managing images quickly and efficiently, causing lists and icons to load faster and smoothly.

```
implementation 'com.github.bumptech.glide:glide:4.0.0'
```

⁸<https://getbootstrap.com/>

⁹<https://d3js.org/>

¹⁰<https://jquery.com/>

¹¹<https://github.com/bumptech/glide>

4.2.2 Background workflow and Interaction concerns

From the field to the paper report it takes a considerable amount of work, what is just a click for a clinician in Datapark and Datapark mobile is a huge list of orders to attend and process. This section will address the servers and Android application work-flow required to process each of the actions that a clinician can perform during a full patient analysis.

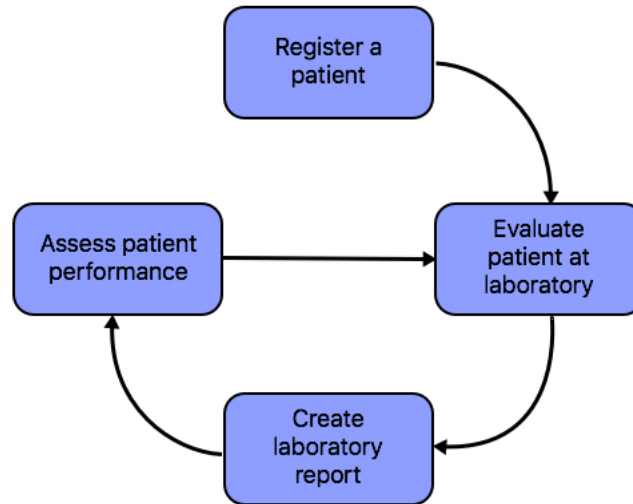


Figure 4.14: Life cycle of a Parkinson's laboratory analysis.

In the figure 4.14 we can visualize the consultation cycle in four major activities, where the first one that is the patient creation in our database is only performed once is the way I separate a full evaluation.

Front and main page

Starting with the front page of the Datapark system, knowing that the the registration it is not made as usual this page is as simple as it could be, the only possible interaction is with the login button where a clinician can authenticate himself.

A simple resume about each of the modules that incorporate Datapark is also presented at this page so that users can understand the functionality and objectives of our application.

Concluding the log in, the patient is guided to the main page where the layout provided are the one represented at figure 4.15, here we can observe the main panel without a chosen patient by looking at the top right corner and see the "No patient" tag. This is the main menu from our application and every workflow must pass through it, to accomplish a laboratory evaluation report the user must navigate to "Clinical", if the objective is to log out then the "More" options provide a log out functionality and not only this if the user has more permissions, having the possibility to invite new users and edit the existent.

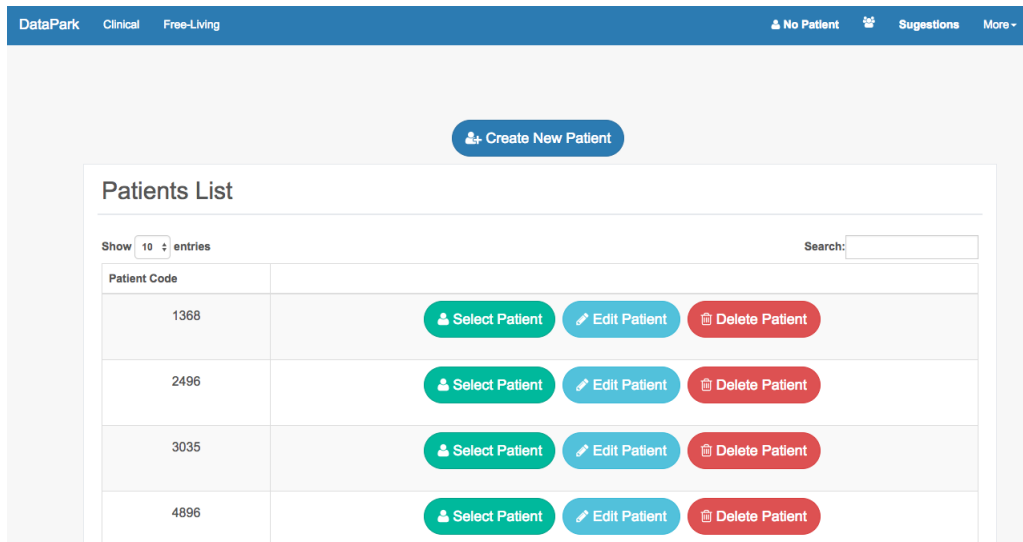


Figure 4.15: Datapark main menu.

Registering and choosing a patient

To evaluate a certain patient this must be registered previously by an authenticated clinician via web application. A clinician starts this step by clicking in the "Create New Patient" button which prompts a modal for this purpose. The registration menu was made to be as simple and less time consuming as it could be, being composed by only four fields, birth date, weight, height and the major identification, the code. In the figure 4.16 we can see this menu used to register a new patient, focusing on simplicity which led to a quickly understanding of the platform workflow by the clinicians and improve the speed with which the actions are performed.

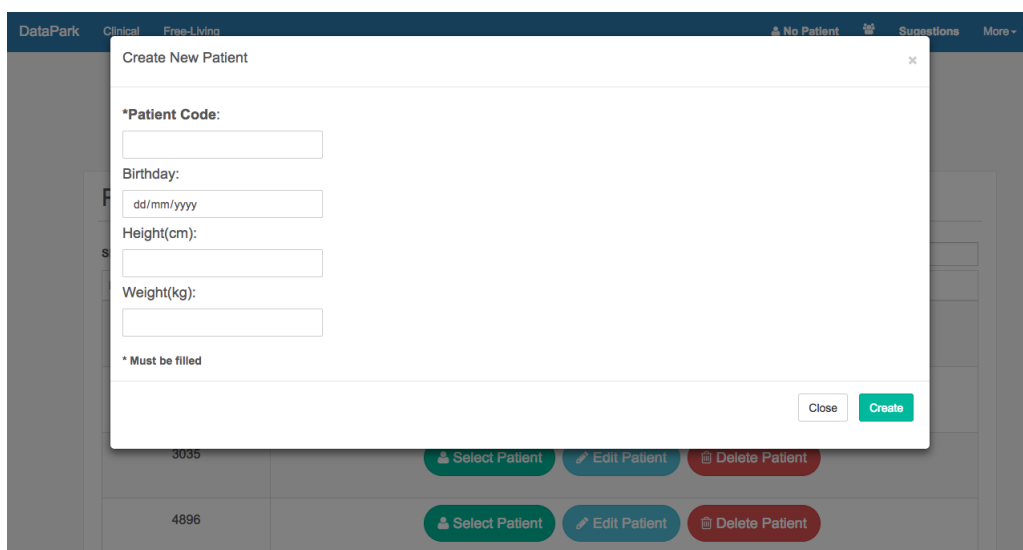


Figure 4.16: Datapark registration menu.

This code is what is used to identify each patient in the different actions that can be done during the usage of Datapark. When no patient exists the default value of "No patient" is chosen by default, where it can be used to store testing data which do not correspond to any patient or simply navigate through the web pages.

To select one patient as current patient the user must navigate through the patients list and select which one of them wants to have as current patient since all the operations done are now regarding merely the current selected patient.



Figure 4.17: Navigation bar with selected patient.

In the figure above it is possible to see the navigation bar when a patient is chosen, changing from "No Patient" to the selected one.

Evaluate a patient at the laboratory

Laboratory evaluation requires the other technology developed by me, the mobile application in consolidation with Axivity Ax3 accelerometer, which are used to help the clinician keeping track of the clinical evaluation without the need of using paper reports or stop-watch to analyze the patients movement at levels that clinicians cannot analyze by observation.

First and foremost the clinician must have previously placed the accelerometer at the desired locations being recommended to place atleast at the lower back (L5 vertebrae) in clinical context.

Thereafter the clinician has the obligation to be authenticated in the mobile application to use it, then it must choose which patient is going to evaluate, by scrolling down in the patient list displayed in the device screen or using the search bar that updates automatically the patient list with each character inserted in the search text box, clicking in the intended patient when it shows up as its shown in Figure 4.18.

Afterwards the patient selection two actions can take place, it is the start of a new evaluation or the system detects that this patient already had a evaluation going on which were interrupted by some event.

Bearing in mind that this patient is performing his ever first evaluation, the action that occur is the jump to a appointment preparation screen (Figure 4.19) where pre-evaluation data must be inserted, current age, weight, height, patient's initial affected side by the disease and where is/are the accelerometer/s being used.

In this screen of preparation of a new evaluation were inserted the fields of text entry and values for all variables described above, however some care was taken in relation to its implementation, the first three being the age, weight and height decided to create only a box of insertion of numeric values, as for the wizard and affected side could only be a

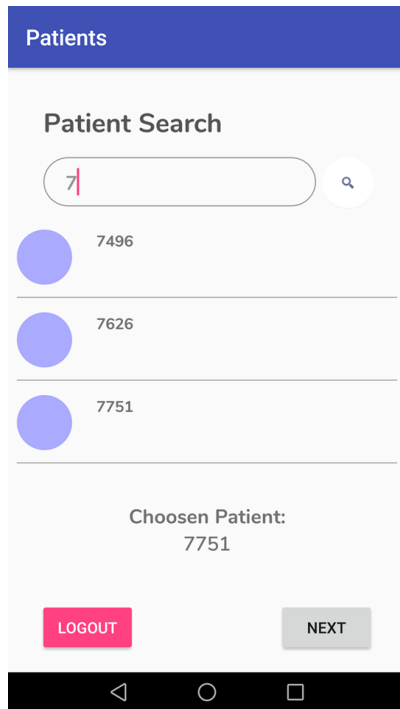


Figure 4.18: Patient list.

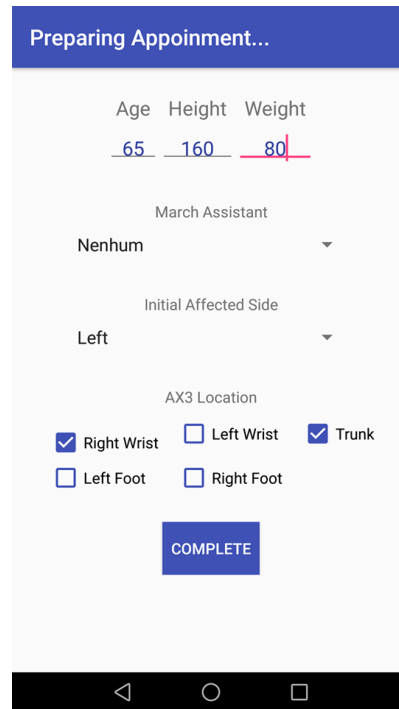


Figure 4.19: Appointment setup.

choice of a hypothesis list I chose to represent the choice using a dropbox for each, and in the meantime I used checkboxes to be able to indicate the multiple places where were placed as not being limited to one.

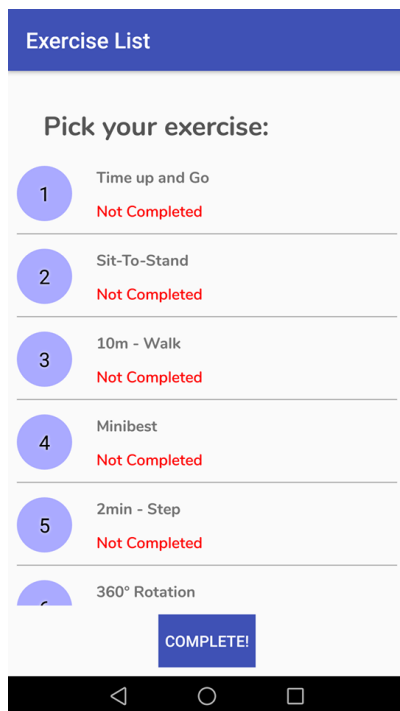


Figure 4.20: Evaluation menu.

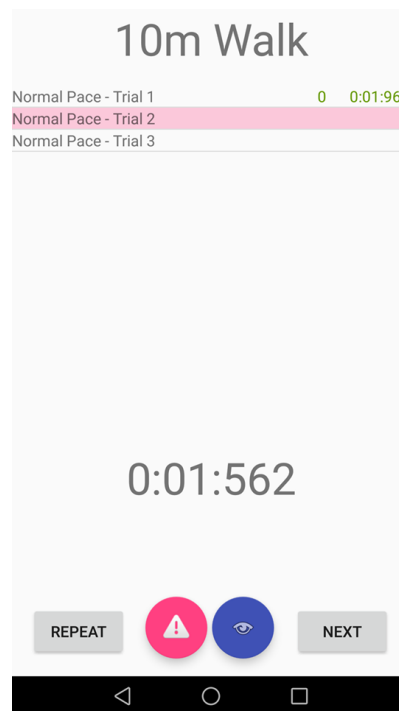


Figure 4.21: Walk Exercise.

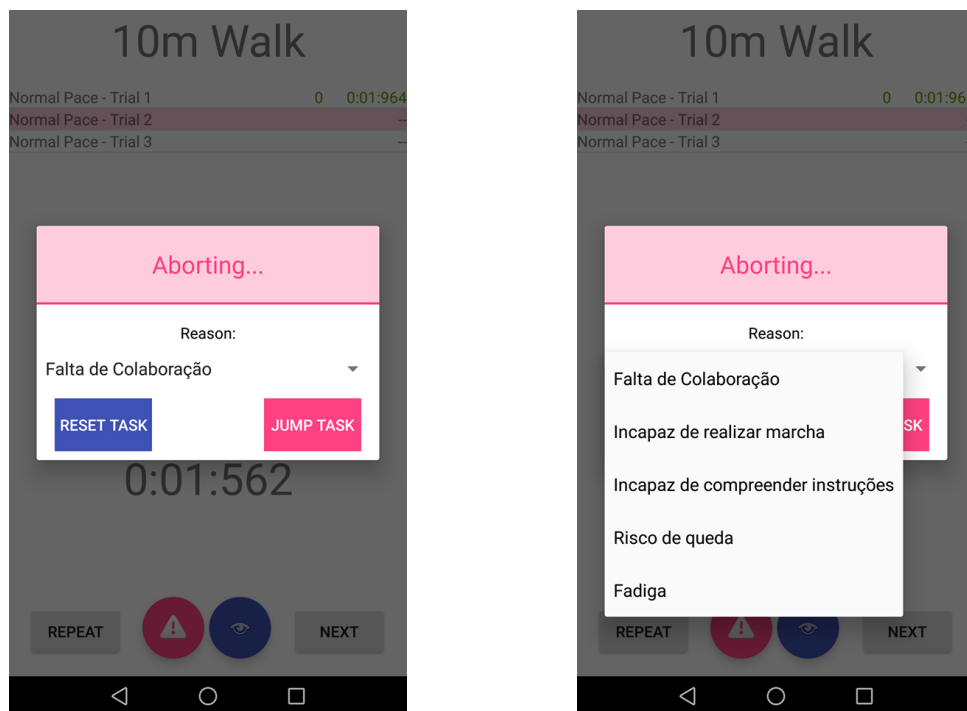


Figure 4.22: Aborting an Exercise.

After this metadata fulfilment the main screen of the Parkinson’s clinical evaluation takes place, Figure 4.20, six entries separated evenly in a list correspond to the six possible exercises used to evaluate the patients motor healthiness and one other button below all the exercises that is intended to mark the end of the evaluation. Clicking in each exercise brings the user to another screen listing tasks that clinicians must evaluate and, they all work the same way when it takes to representing the start and completion of each task and correspondent trials.

Meanwhile, current task is highlighted in the list and there are three buttons on the screen as shown in Figure 4.21, with the objectives of marking the start and end of the current task, possibility to redo the task if anything goes wrong, jumping to the next task and the circle button with the ”danger” sign that is used when the clinician needs to abort or revert all the exercise and picking a explanation for what succeeded.

This danger sign takes the application to show the dialog box, represented in Figure 4.22, in order to understand if the user wants to revert the exercise or choose from the dropbox presented which of the reasons led him to abort the current exercise.

Walk and Tug not only has what was previous explained but also adds a initial interaction with the clinician to store information about which dual-task is used to each exercise and if the patients are using any help or march support as shown at the left in Figure 4.23. At the right of the same figure we can see the Step exercise preparation by showing a dialog box where the user must insert the data correspondent to heartbeat, oxygen saturation and Borg scale pain value.

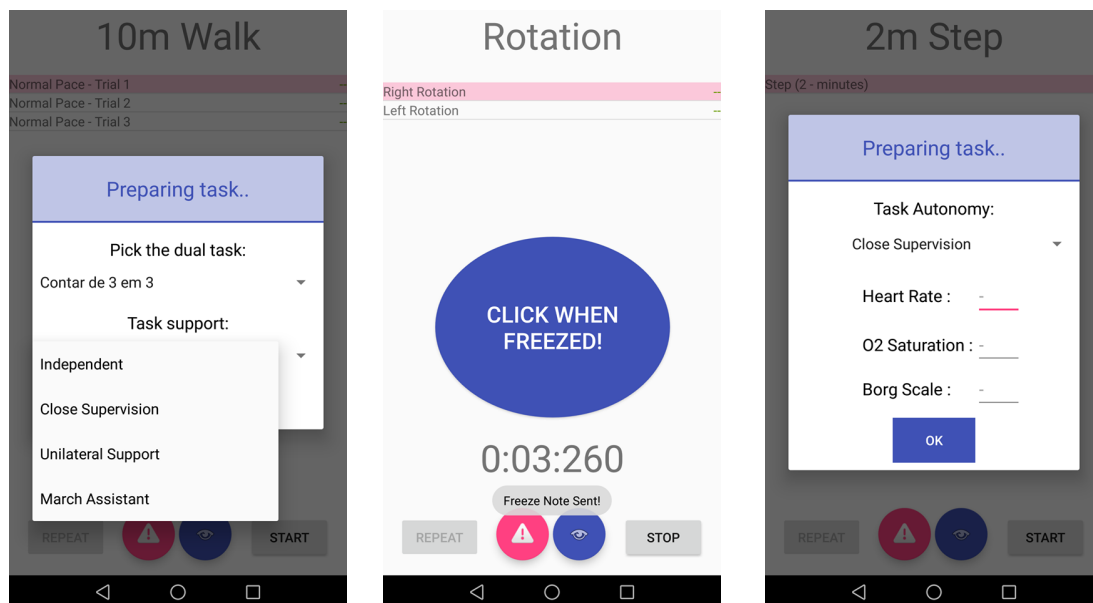


Figure 4.23: Exercise preparation and different interactions.

Balance and Rotation both had a little different interaction where in addition to the previous actions, after each task of the balance evaluation the clinicians fills a little "pop up" where he must decide which was the classification of the patients performance. Rotation has a big round button where the clinicians clicks to point out the moments of movement freezing during the execution of this exercise (middle of Figure 4.23).

After all these performances are complete or those which the clinician chooses to evaluate, he can mark this laboratory evaluation as complete clicking in the only button of the main menu that is used to end the clinical evaluation and creates one entry of an Android Report in the selected patient location at the database.

However, another work-flow happens when instead of being the first evaluation, this patient was already being examined and for some reason the mobile app stopped or something wrong happened. When the device verifies which patient is chosen it also confirms if this patient was already under an evaluation that was not marked as complete and restores the previous session with the data until there collected.

Creating a laboratory evaluation report

After the physical evaluation in the clinical context the accelerometers are removed from the patient and using the AX3 GUI present at the first section of this Chapter in the figure 4.1, the .cwa files are obtained and stored at the file manager of the device used.

This third part of the clinical evaluation process is done only by the clinician, thus, he must open Datapark web app front page, authenticate himself and then select which patient made the evaluation to mark him as current patient. Meantime there is a button at the top left of the page called "Clinical" where the user must click to open Laboratory

Report page of the selected patient and then click in "Upload File" as we can see in the figure 4.24.

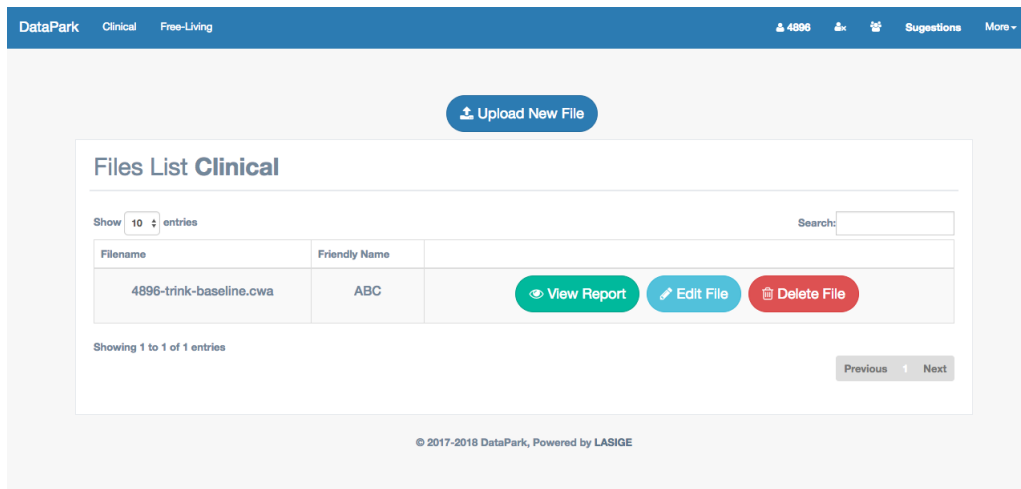


Figure 4.24: Clinical context menu.

In the report creation page there is upload box which is used to upload the signal file obtained earlier to the database. It is important to fulfill the dropbox that indicates from which part of the body this signal comes from, choosing the Android Report relative to this evaluation and giving this report a name to be later on identified by the clinician. If this android report has the age, weight and height fields filled the creation process is complete and the user just needs to confirm, otherwise, the clinician has those three fields to fill on the creation form beyond the accelerometer location and confirm afterwards.

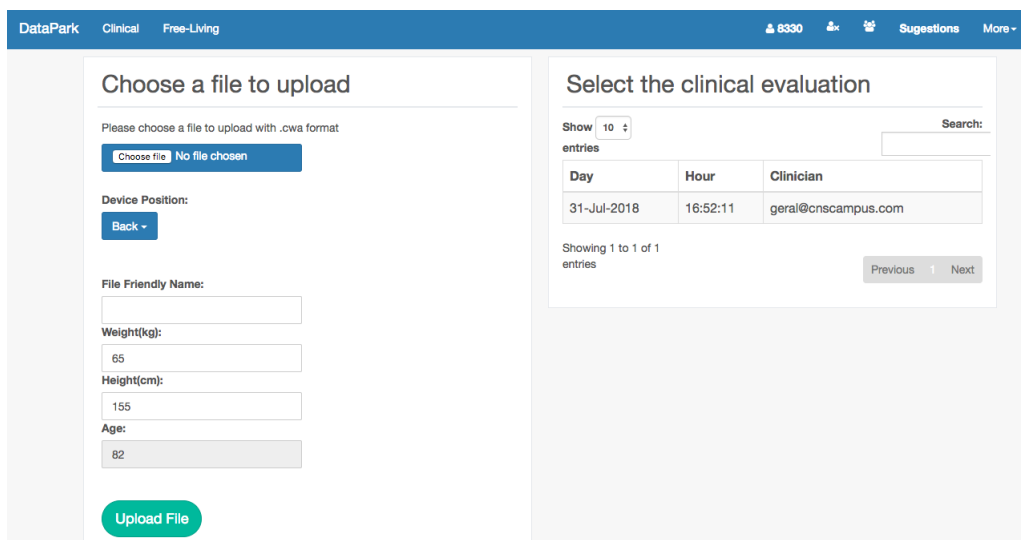


Figure 4.25: Laboratory report upload example.

Assess patient's performance

To assess patients performances all the previous steps need to be complete and the clinician once more needs to be authenticated using the web app and with the respective patient selected as current patient, thereon the user must chose the Lab Report page of this patient containing a list of all Laboratory reports created and clicking the "view report" option of the desired one. In case of some error or mistake it is also possible to edit or delete the report.

Hereafter it will open a loading bar that is processing the correspondent .cwa file making a call to the web service containing the .cwa to .csv adapter and after this conversion, fetching the resultant file from the database and process it using algorithms explained in the following section providing then a report where the clinician can navigate and verify the patient performance during every exercise performed during the evaluation, in figure 4.26 we can see an example of a generated report including both signal and android data.

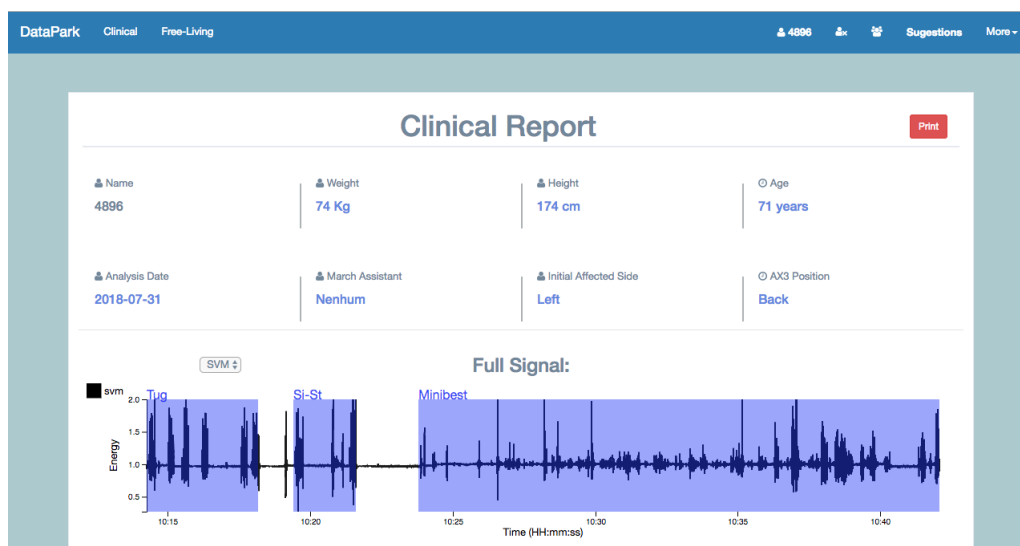


Figure 4.26: Automatically generated laboratory report example.

4.3 Supporting clinicians in exercise evaluation

During the performance of an exercise, minor fluctuations which can lead to major indicators of the patients disease evolution cannot be observed by the clinician. Starting with the clinician's attention and focus that are both on the patient's risk of fall and security, to the inability of measuring/detecting fluctuations seemingly impossible to see, there is a large quantity of factors why it is an improvement in medicine, more properly in the Parkinson's fluctuations detection, to insert mechanic devices to measure and obtain data from movements that cannot be observed at naked eye.

This section consist in the enumeration of the exercises evaluated using the AxivityAX3, its algorithms, which metrics are obtained and the importance of each one of them.

4.3.1 Energy

The first and most basic metric obtained was the energy measure of the signal obtained from the axivity, the energy metric was the values of energy spent during a certain period of time, i.e accelerations of each axis combined using the figure 4.2 equation.

$$Energy = mc^2 \quad (4.1)$$

This metric expressing the combination of the accelerometer three axis values, which when applying the Einstein's energy equation 4.1 and using as the parameters the acceleration and person's weight it gives the energy spent during that acceleration expressed in calories.

4.3.2 Posture Transition

Posture transition is the metric used to automatically detect and evaluate the sit-stand and stand-sit changes. Based on the literature review, most of the algorithms were based on the solution presented by Bidargaddi's paper [1]. First, the three axis from the accelerometer were combined in one signal vector magnitude (SVM), where giving the three vectors corresponding of each three axis (x,y,z) and removing the 1g value of the gravity acceleration, each position of the SVM vector was calculated using the equation:

$$Signal\ Vector\ Magnitude = \sqrt{(x^2 + y^2 + z^2)} - 1 \quad (4.2)$$

After the integration of all the axis into one, a 5th order Meyer digital wavelet transformation function was applied, this function is used to reconstruct the wavelet and eliminates the noise effect existent in the signal providing a smoother and more accurate wavelet to be evaluated. Python's pywt library already has functions implemented that perform this multilevel reconstruction of wavelets¹².

The previous steps are the preparation used to integrate all the accelerations into one and cleaning the noise existent in the process of acceleration collection, from here the following steps consisted in clipping the wavelet to the right moment of the exercise which was made using their startTimestamp and duration marked by the clinicians in the Android report correspondent to this signal evaluation.

Thereafter, the signal was processed to obtain its maximum and minimum peaks giving a list of values that are then computed to understand from their order if they correspond

¹²<https://pywavelets.readthedocs.io/en/latest/ref/idwt-inverse-discrete-wavelet-transform.html>

to a Sit-Stand or a Stand-Sit transitions, as explained in previous chapters this exercise involves 5 times this repetitions which do not go according the one transition observated by Bidargaddi's study, then, I had to solve algorithmically this setback by using the max-min peaks order.

After each transition is found their duration are calculated using the same validated method as the study, multiplying by two the temporal difference from the max and min peaks of each transitions, thus, obtaining this way a set with all the transitions and their relative durations. In the Figure 4.27 it is possible to observe a wavelet where two posture transitions are represented, at yellow the sit stand movement marked by one maximum peak followed by a minimum peak and contrariwise, in orange, the stand-sit movement.

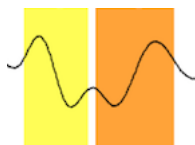


Figure 4.27: Posture transition wavelet.

Each rectangle's size correspond to the temporal window where all the movement occurred from the first inclination made to the final position. This figure represents the final wavelet obtained after completing all the steps previously described.

4.3.3 Balance

Evaluating balance required understanding which axis were being used and which axis should we evaluate, understanding that the positioning of the accelerometer on the patient is a major factor to the well functioning of the algorithms that will be presented.

Having the knowledge that the balance exercise is divided in 16 different trials, evaluating distinct axis and each one having diverse duration made me decide that each balance exercise should be processed separately. Thus, in Datapark UI the user can see a table listing all the balance exercises and the resumed metrics of each exercise, from here it is possible to click in any of the performed tasks and an Ajax post is sent to the server where he process the balance metrics.

The server's duty is to fetch the .csv file previously stored at the database and starting by clipping the data correspondent to each part of the Balance evaluations, a time window was created using the chosen task starting timestamp and the end of it is calculated using the sum of the prior value with the task duration, giving this way, the window corresponding to the chosen task.

In terms of algorithms, were implemented and used algorithms according to the literature review. Jerk, Figure 2.1 and RMS, Figure 2.2 were the two algorithms implemented to evaluate the patients balance. However, some studies defended an application of these metrics for both AntePosterior and Medio-Lateral axis combined and others to the same

separated, thus, to evaluate a balance task a clinician will have five metrics, frontal, lateral, double axis Jerk representing the combination of the frontal and lateral and also frontal and lateral RMS.

- Jerk - Corresponds to the rate of change in acceleration. The units will be the currently selected acceleration units/second.
- RMS - Represents a measure of the imperfection of the wavelet. Basically a sin wave has its periods all equal, then RMS will evaluate it with "better" classification than a wave without similar periods.

Implementing these two algorithms gives clinicians enough tools to start evaluating balance with new tools, metrics and validated algorithms that are not subjective as the common "observation" process.

4.3.4 Step

Step metrics were the most expected by clinicians because they can be removed from an accelerometer and there is no need for larger devices such as the GaitRite mat described in the literature review section or other more expensive mechanisms.

In algorithmic terms it worked like the previous ones where the file was initially processed from .cwa to .csv with intervals of 100ms and passed a low pass filter. After this pre-processing, the means and standard deviations of the axial vectors were performed and added.

From here onwards the methodology known in the Hickey study [16], where the acceleration orientations are calculated, and using a Gaussian CWT (continuous wavelet transformation) were estimated the IC and FC values corresponding to a list of initial and final points of contact, respectively.

From the points of contact and acceleration the number of steps, the average distance between them, speed of course and their variations were estimated having in mind the weight and height of the patient. This way I obtained a set of validated metrics that can be used to objectively evaluate a patient in terms of his walk.

4.4 Data visualization and reporting

Prior sections focused in the application work-flow and obtaining exercise metrics using algorithms, in this last section will be addressed the way I put collected data arranged in the application. Each of the exercises had their own specific information and this led to some challenges in terms of data visualizations. Thus, I tried to simplify the data navigation through exercises and to create a simple template inside each one of them



Figure 4.28: Laboratory report common info and exercise navigation.

so that the common information can be always found in the same places regardless the exercise.

As first example we can notice that this eight top fields at the Figure 4.28 represent the data that is common to all exercises. However, there is a line chart below that represents which is not a metric but represents the energy used overtime and the time window in which each exercise was performed, clicking in the dropdown currently marked with "SVM" opens the possibility to transform the graph to show the raw X,Y and Z values in the same temporal window.

4.4.1 Specific data visualization

The static common patient header is present every time but, as it can be seen, just below the activity chart in the figure 4.28 there is a horizontal navigation panel with the exercises used to evaluate the patient during the clinical evaluation. Clicking in each of this navigation tabs will open the information specific for this exercise.

Timed up and Go

Timed up and Go was evaluated by the duration of each trial and a mean value of them, if a trial has a duration above 7,5 seconds it is considered as a possible risk of fall.

In the Figure 4.29 is possible to observe a table that is used to represent the data from all the trials, duration, mean time and which dual task was used and a chart used to compare graphically the duration of each trial. The red value of the bar chart bars

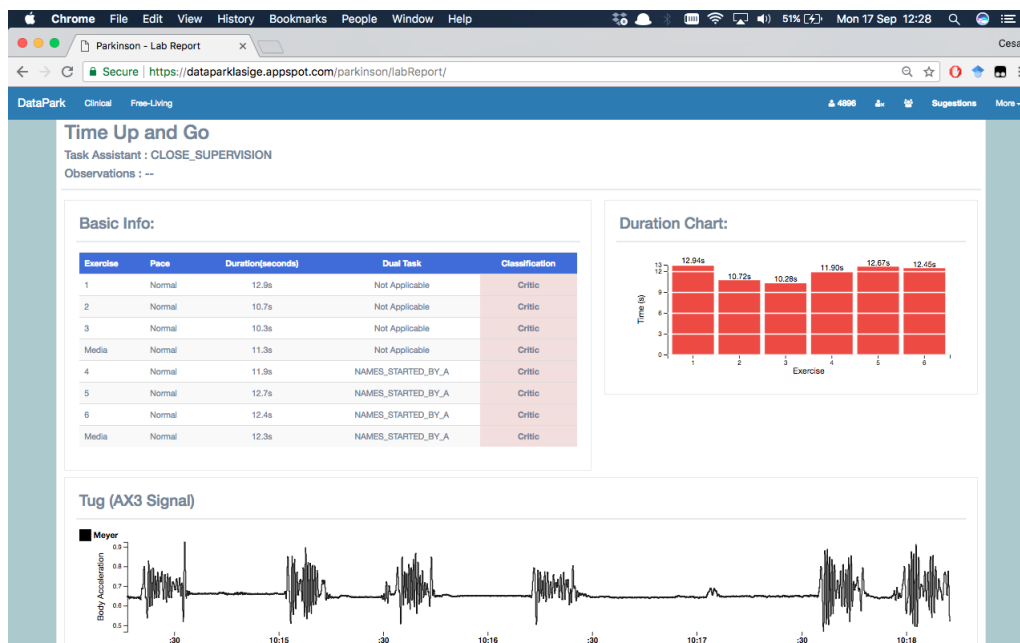


Figure 4.29: Laboratory report Timed up and Go tab.

and table rows is telling the clinician that all these trials were considered as a risk of fall indicator.

Right below it can be seen a line chart, where each of those irregularities are one TUG exercise, this chart can be used to confirm possible risk of fall theories by looking into major peaks on it or even compare effort / energy used to perform each trial.

Sit to Stand

Sit to stand contains all the posture transition metrics already explained in the previous section. Therefore using a collection of tables and interactions between them I have implemented a layout in this tab in order to simplify finding meaningful data.

There are three tables In the Figure 4.30, representing all the metrics described above, having the knowledge that this exercise is composed by two trials I had to incorporate all the information in this page without confusing the clinician. Therefore, in the first table where we see the duration of each trial, we can click on which we want and the tables update the values for that particular one.

Lastly, at the bottom of the screen it is possible to see the signal chart and, marked with different colors, it is possible to differentiate each transition and using its correspondent number check in the table above how long was it. This chart also updates to the current clicked trial when the user changes it.



Figure 4.30: Laboratory report Sit to Stand tab.

Walk

As in TUG this exercise is performed and evaluated using the duration as main factor to evaluate if some patient has or not risk of falling, however, inserting a set of metrics about the patient’s walk performance was appreciated and hugely expected.



Figure 4.31: Laboratory report walk duration charts.

Figure 4.31 represents each walk trials and respective duration, number of steps annotated by the clinicians and a bar chart to easily observe the evolution of each trial in terms of performance time. Right below this charts there is a table as the one in the Figure 4.32 that discriminates all the step metrics obtained by processing the AX3 signal, these metrics correspond to the mean values during all the Walk exercise performance.

Represented with a green ”correct” symbol are the values which are within the recommended values and with red ”arrows” are the ones o are above or below, changing also the arrow direction, the recommended values.

Pace

Metric	Reference	Obtained	Classification
Number of steps	--	39	--
Step Length(m)	0.335-0.821	0.280	↓ -0.055
Step Length Variability(m)	0.061-0.243	0.072	✓
Step Length Asymmetry(m)	0.016-0.158	0.029	✓
Step Time(s)	0.287-0.923	0.627	✓
Step Time Variability(s)	0.002-0.360	0.134	✓
Step Time Asymmetry(s)	0.025-0.338	0.057	✓
Step Velocity(m/s)	0.591-1.443	0.467	↓ -0.124
Step Velocity Variability(m/s)	0.141-0.583	0.169	✓
Stance Time(s)	0.322-1.190	0.141	↓ -0.181
Stance Time Variability(s)	0.017-0.445	0.147	✓
Stance Time Asymmetry(s)	0.070-0.231	0.034	↓ -0.036
Swing Time(s)	0.206-0.710	0.486	✓
Swing Time Variability(s)	0.017-0.285	0.180	✓
Swing Time Asymmetry(s)	0.015-0.224	0.023	✓

Figure 4.32: Laboratory report step metrics.

Balance

As explained earlier, this exercise consisted of the greater number of tasks performed during the entire clinical trial and all tasks diverged greatly between them, so this led me to have to apply a simple layout and instead of presenting everything at a time I present only the base. The clinician can choose which trial wants to evaluate in detail and obtain it with 1 click, showing all the information about it.

Minibest
Observations : --

Exercise	Description	Duration(Seconds)	Points	Classification
1	Sit To Stand	0.6s	2	Normal
2	Rise To Toes	0.4s	0	Severe
3	Stand On One Leg (Left_Trial 1)	30.6s	2	Normal
4	Stand On One Leg (Left_Trial 2)	30.6s	2	Normal
5	Stand On One Leg (Right_Trial 1)	28.9s	2	Normal
6	Stand On One Leg (Right_Trial 2)	30.7s	2	Normal
7	Compensatory Stepping Correction (Forward)	0.4s	2	Normal
8	Compensatory Stepping Correction (Backward)	0.5s	1	Moderate
9	Compensatory Stepping Correction (Lateral)	0.5s	2	Normal
10	Stance (Feet Together EyesOpen FirmSurface)	0.3s	2	Normal
11	Stance (Feet Together EyesClose FoamSurface)	30.9s	2	Normal
12	Incline Eyes Closed	30.9s	2	Normal
13	Change in Gait Speed	0.7s	2	Normal
14	Walk With Head Turns Horizontal	0.8s	1	Moderate
15	Walk With Pivot Turns	0.6s	2	Normal
16	Step Over Obstacles	0.7s	2	Normal
TOTAL	Combined	168s	28	Success

Axis	Jerk (mm/s²)	RMS	Critical Oscillations
Anteroposterior	0.004 mm/s² 0.077 +/- 0.031	0.077 +/- 0.031	0
MedioLateral	0.494 mm/s² 0.927 +/- 0.202	0.927 +/- 0.202	0
Combined:	0.927 mm/s²	--	0

Hint: Select an exercise / row.

Figure 4.33: Laboratory report balance duration charts.

In the Figure 4.33, we can see on the left the complete list with all its durations, descriptions and evaluation of the patient's clinic. If it was a bad evaluation the whole line of this task is presented with a reddish color as it is in the second exercise of this example. Finally it is possible in this same table to verify the final evaluation comparing the sum of the evaluations to a previously tabulated value and thus verifying if this patient should be considered or not with possible risk of fall.

By clicking on one of these tasks, the table on the right is updated to the values corresponding to the one of the selected task, this gives the clinician a dynamism and simplicity in the data visualization that would not have if they were all fully described.

Step

Finally we have the Step exercise that ends with a set of metrics not processed but of high importance for the clinical analysis, where what matters is the comparison of three values of the beginning and end of performance and ,for this reason, I decided to present these measures as it is in figure 4.34.

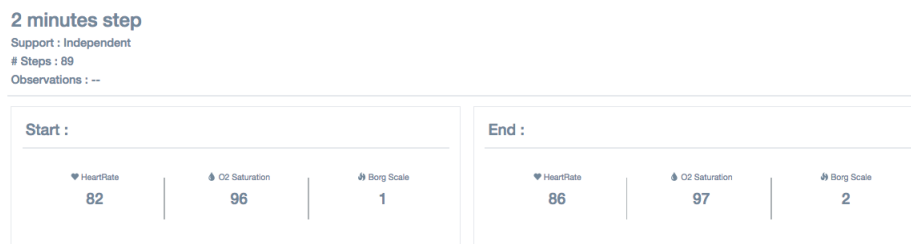


Figure 4.34: Laboratory report walk duration charts.

4.4.2 Data reporting

In addition to presenting the information in a dynamic and easily navigable way, to the clinicians, it was decided that it would be important to find a method of exporting the data to paper in order to be discussed by clinicians and patients in a more direct way.

With this objective an additional function was created in the platform whose function is to print the open report, for this impression the most important data of the analysis were chosen so as not to saturate information which should be easily read and interpreted.

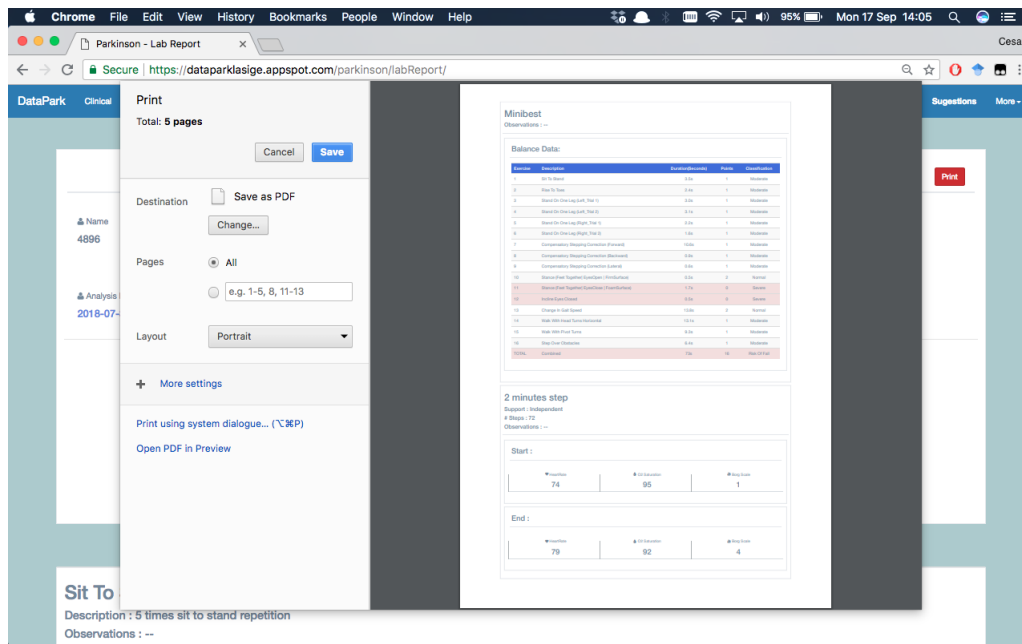


Figure 4.35: Laboratory report print window.

In figure 4.35 is the window that opens, after clicking the print button that is in the common information area of the patient as shown in the figure 4.28, with the preview of the report at the time of printing .

Chapter 5

Evaluation

This chapter involves all the evaluation made to Datapark, this is the chapter that verifies its importance in the treatment and monitoring of Parkinson's, it is a fundamental chapter of this thesis and for its success. It was precious to connect with CNS organization which made it possible to perform these assessments with accredited professionals and with a set of people with the state of health necessary to use Datapark.

The results of this section will demonstrate if Datapark was really helpful assisting clinicians in supporting and monitoring patients with Parkinson's and whether the stipulated goals have been met.

For this purpose, two studies were conducted in which different participants entered and different tests were carried out. A discussion session after the first one and a questionnaire after the second one were used to understand the opinion of the clinicians after using the platform in an unsupervised context.

5.1 Spring Campus Week Study

During the execution of this thesis we had the hypothesis of participating in a campus week at CNS, this was defined as an objective and I decided to focus on rushing the implementation in order to begin this first study with a stable version of the system.

A CNS campus consists in a set of patients meeting at the CNS center for a week to have assessments, lectures, and other activities on the subject of their illness. This week of uncontrolled use had the necessary to tell us whether or not the existence of the platform is useful to monitor people with their limitations.

5.1.1 Goals

To perform this study, we discussed the participation of 3 clinicians, where one of them corresponds to the one that facilitated the collection of information, knowledge and requirements for the elaboration of the system, allowing the possibility of observing and

discussing the execution of Parkinson's consultations in clinical context previously described in the third chapter of this thesis.

Once the Datapark insertion was accepted and combined in the study, and aiming to induce the use of the platform in a longitudinal context in a single week, the objectives were focused on the use, acceptance and perceived effectiveness of the system as one by clinicians, i.e, the different opinions and uses of both web app and also Android application to help each evaluation.

This study was conducted in order to obtain answers to the following research questions:

1. Test the acceptance of our system by the clinicians by understanding how do clinicians react to technology based assessment? How do clinicians understand and feel comfortable using technology instead of paper guides during evaluations?
2. Is it possible to insert a system that improves current Parkinson treatment practices? How meaningful are Datapark reports and how do clinicians cope and benefit from it?
3. Does the web app and application reports help in the patient - clinician relationship during evaluation and discussion sessions?

5.1.2 Participants

The participants of this evaluation were those who were accepted to participate in the CNS Spring campus. In addition to the patients, 2 physiotherapists and 1 clinician also entered to evaluate each participant. Patient inclusion criteria:

- Patients diagnosed with Parkinson's disease;
- Being interested in participating in the study;
- Patients who stayed from the first day to the last of the campus;
- Patients in non-extremely advanced Parkinson's states, where it is still possible to perform physical tests of easy or moderate difficulty.

After this screening, seven patients were chosen to participate in this study, being previously informed and giving their consent.

5.1.3 Methodology

Since the duration of this study was very limited to one week and during this week the whole plan of activities and evaluations was already well defined, it was relatively easy to insert the evaluations using our system at the established time.

- **Day 0:** Before the start of the campus we conducted a discussion and description of the protocol used during the week study with physiotherapists, presentation of the Datapark system, Android application deployment to clinicians phones and registering in our system each clinician as a new user.
- **Day 1:** On the first day of the campus the patients' records were started on the platform and the first evaluations were carried out in their entirety without our help. After performing the evaluations using the sensors and smart phones with the mobile application the data collected with the sensors was obtained and the initial reports were created.
- **Day 1 to 7:** During this period there were no more marked analyzes in the time presented initially for the Campus, however we left a version running at CNS so that if there was a need for clinical evaluation the system would be ready and working, which was useful because there was a patient who had to be reevaluated and the mobile application was then used during that week without our presence or support.
- **Day 7:** This being the last day of the campus, a few more activities were carried out and finally a reassessment of the physical condition of the patients was done in clinical context. Again using the mobile application, sensors and later creating and obtaining the reports the physiotherapists evaluated all patients and obtained their respective reports. A small informal interview was conducted between us and the physiotherapists who evaluated Parkinson's patients to see if there were any problems or drawbacks during the performance.

In addition to the information collected during the interviews logs, uses, clicks, number of reports, patients and suggestions were also collected in the form of logs by our platform.

5.1.4 Analysis

After campus week a discussion was held about how was the use of the Datapark both web app and android application with one of the clinicians. As there was no availability for a formal interview, I and another researcher noted during the discussion the important points in order to note down the advantages, problems and possible advances in the system.

After taking this notes we meet and put together all the common concepts collected and discussed which do not coincide as well to understand if it is worth having in count or not during the evaluation of the system.

The following section will address every aspect gathered during our reunions with clinicians and discuss what led to which conclusion by them.

5.1.5 Results

During this study there were no major problems, however contrary to what was indicated at the beginning the sensors instead of placed during only the evaluation of each of the patients, were placed all at the same time and removed in the same way, that is to say the last patients had the sensors for about 3 hours which delayed for a few seconds the processing time of the files to the .csv format.

Due to an error of organization the reassessment accelerometer of one patients was lost and we did not know which accelerometer coincided with the patient in question and, when the accelerometers were all collected, we would have to test one by one until we found out which one was right, and that would take a lot of time, time that we did not have at that time.

Also during an evaluation there was a case where the mobile application froze and stopped working and, after reopening it, the data from this assessment was lost, this caused the need to a reevaluation.

Mobile Application

It was interesting to note the use of the mobile application during the evaluation because it was not the traditional practice and many of the clinicians and physiotherapists were getting used to it, a battery of thanks and requests for improvement were made in relation to this application. Comparing the initial evaluation with the re-evaluation the ease of use related by clinicians was admirably superior, so we concluded that in terms of usability the application is on a good course and easy to use.

"This chronometer here in the application it works great, it saves us the need to walk with a watch or another device in your hand while we do the exercises." - Clinician

Since the beginning of the use of the android application, the physiotherapists have approved the timer that appears showing the time of the exercise, since it is a factor that they need to be controlling and this way they have a greater facility in this task.

"How do I skip just one task from one of the exercises and not the whole exercise?" - Physiotherapist

During the initial evaluations there were some questions like the one above, very much related to what to do in relation to jumping only one trial and not an entire exercise. This was explained to the clinicians in the meantime that it was impossible to mime in the moment using the current application version. The reason explained was because when it was implemented it was taking into account that when doing an exercise, all trial would be completed.

However, to solve this problem, we indicated that the trials that they wanted to go ahead, they simply need to click Start and then Stop, quickly, giving a duration of tenths of seconds in the stopwatch that would later be ignored in the web application when processing metrics.

"Is it possible to pick which exercise I want to perform without having to do them for this certain order?" - Physiotherapist

One of the observations to be taken into account was exactly the one presented above, sometimes the clinicians preferred to follow an order of exercises other than that of the protocol and since the application was in a version where the protocol exercises were performed in an orderly manner. There were some comments in relation to the possibility of increasing the modularity and controllability for the user.

For some clinicians that did not know correctly what was the study protocol it was harder to understand which exercise was supposed to do, this led to some conclusions from my part where an instruction guide or hints in the app might be necessary. As well as hints for the ones who do not know which data should they save at a given exercise, for example, at the middle of the first walk assessment:

"What are you supposed to put in this field where it says "steps"?" - Physiotherapist

"There is an overhead of actions to make by the double use of paper and app, so it was difficult to evaluate the benefits connected to the use of the app." - Clinician

This comments were answered with the need to put both, there and on paper, the number of steps made in this trial of the exercise to exist data redundancy, since this is a test of our application and all data must be replicated.

"If the application returns, is it possible to recover the data from the last evaluation?" - Clinician

To finish the observations of the application the question above was posed, to which it was answered affirmatively and with the promise that it would improve the application so it does not exist loss of information in cases of failure or error in the mobile application.

Evaluation reports

Regarding the generation of reports does not have much to be pointed or commented since only two reports have been received for each patient. Due to having a start and end report there was agreement from clinicians that the possibility of comparing reports would be a feature to insert and vastly used.

Besides the reports themselves, there were no points pointed out about the data offered, but their beauty, colors, layout and beautification were discussed by inserting the color differences for patients whose performance represents a risk of falling and for those who do not.

Colors, layout and location of charts were discussed and changes were taken into account to make a report stand out best for clinicians and patients. The ability to print reports has always been appreciated and valued since it is necessary at the clinical level to simplify the comparison and discussion, answering the question purposed by one clinician that was:

”How would we be able to export these data once we have them open on the application page?”

Improvements

Finally, conclusions were drawn from this study and it was decided that improvements should be made to both web and mobile applications and the following changes had to be made, in order of priority:

1. Data replication and last evaluation retrieval in case of crash or problems with the mobile application;
2. Improve the modularity of the mobile application where the protocol can be modified and executed in order of preference by the clinician and not in linear order as it was at the time;
3. Possibility to stop an appointment and re-execute later if it is not possible to evaluate everything at once;
4. Improve the quality of visual reports;
5. Be able to skip some tasks that are not necessary to evaluate;
6. Add a new exercise that includes a rotation of 360° in both directions and whose number of freezes should be saved;
7. Minor changes in terms of the data collected in the mobile application and how is it collected, i.e. accepting floating numbers in the Step exercise scales, insertion of observations in the application and addition of one more task in the balance battery.

5.2 Longitudinal Study

After carrying out the previous study and solving most of the improvements and problems described, our system was ready to be used in a large study, now available to a longitudinal study, not limited to just one week with the expectation of improving the medical interest in using it with new patients and, therefore, leading to more data and future melioration.

Previously, in the first study, patients were under a certain condition of dementia, all being considered old patients with already detected and diagnosed Parkinson's disease. However, CNS also receives middle-aged and young individuals with signals of this condition, thus, opening the radius of patients that are evaluated using our platform for a wider range.

A longitudinal study was accorded with CNS where Datapark was ready to be used without being under observation or having any help provided by us, researchers. This study was agreed by both parts and it will keep running after my thesis ends, however, the information available for this section is what is available at the time this is being written.

5.2.1 Goals

For this long-term study, different objectives of the one week campus were defined, the need to verify if the impact of the system in the evaluation of patients was positive from the generated reports, and whether the use of the mobile application improved the performance of the clinicians in the evaluations were overcome and now sought to have a platform validation at a clinical level.

To be certain of the usefulness of the platform and if its validity defined as objectives the compliance and continuous use of the platform, which represents its value and importance in the Parkinson's assessment and the validity of the information obtained, i.e, if the data is correct, meaningful and consistent to correctly evaluate patients.

5.2.2 Participants

During this study we did not had a limit of participants, however, having in mind this study has the duration of about two months and that we have access to every account that logged on our system as well as the amounts of clicks, reports and patients evaluated, during this period we count 5 different users logging in.

Apart from the user logging in, there were 11 different patients evaluated using our system by those clinicians, considering that every patient evaluated follows the similar criteria as the ones recruited in the prior study:

- Patients diagnosed with Parkinson's disease;
- Being interested in participating in the study;

- Patients in non-extremely advanced Parkinson's state;

5.2.3 Methodology

This study with a longer duration started by delivering a use protocol with instructions (Appendix A) to guide any health professional willing to using it to perform an evaluation. Meanwhile, after around two months a questionnaire was sent to the clinicians that used our system in order to obtain information about Datapark's validity, the full questionnaire can be found in the Appendix B.

5.2.4 Results

After conducting the questionnaire, three clinicians have answered and the results were not much different than the observations and ideas taken from the first study. Therefore, the pool that answered our quiz is composed by three female physiotherapists, all with less than 40 years, two of them defending that they evaluated a total of 4 patients each, and the last one accomplishing evaluations with 10 different patients. Bearing in mind that the same patient could have been assessed by more than one person this information goes according the data presented from our system logs.

From questionnaire's data collected it is possible to see an agreement in the nonexistence of negative implication while using the Android application during evaluations. As well as the concordance in the receptivity of all assessed patients in terms of good acceptance about wearing accelerometers.

Overall the use and learning curve of the application were considered as being medium-low, where most of the problems being about specific crashes that led to the re-opening of the application and re-execution of the task that was being performed when the application crashed, instead of being about usability or difficulties while performing each exercise.

All of the physiotherapists also used the web application after clinical evaluations and all felt low difficulties while using it, however, some suggestions were made:

"They could be more intuitive or have more captions to explain the graphs and how it was calculated. Also, have better print versions."

Thereafter, one clinician discussed printed reports with its patients and defended that they could not easily understand what was expressed in each section of the reports, which goes accordingly the previous quote. However, there was an 100% agreement in the improvement of knowledge about a patient using our generated reports by all subjects. Also, there were multiple statements about what they appreciate having in the reports:

"The information that allows us to signal the patients risk of falling and the gait parameters that we can work on";

"Facilitates comparison with subsequent evaluations";

"I found it helpful to know how long it took the patient to rise and sit".

5.3 Discussion

During both studies, we found strong indicators representing the willingness of clinicians to have technology associated with the evaluation of Parkinson's, however, it is also difficult to make the complete insertion of these platforms in the current methodology.

Regarding the generation of automatic reports, this was well received, however, after checking the readability of both clinicians and patients the last ones showed difficulties in understanding what some data represented. This promotes the idea that there is a need to improve the reports created and perhaps create a new type of report that is simpler and with fewer scales and scientific data in order to be more readable by patients.

Meanwhile, the android application was the focus of most interest during the consultations, suffered both positive and negative critics in some points but the interest in using the application to replace the traditional method was evident. However, it was impossible to evaluate the appointment duration using only the Datapark mobile because the annotations were done in parallel with the mobile phone and in the traditional method of paper report.

Keeping in mind that the android application was the focus of user criticism and interest, it is necessary to focus heavily on improving and refining all parts of this application so that future studies can be performed without the need to replicate information using traditional methods.

We came to a point where, with these studies, we understand that there should be improvements to be made in several components, but it was a success to use a platform both for the purposes of data obtained and to make known to clinicians' new types of tools to improve the studies of people with Parkinson's.

Chapter 6

Conclusions

This section will address the objectives set out in the first chapter of this thesis. From now on it is necessary to point out that the observations and initial discussions were the great drivers for a good start and definition of what this project was. In addition, they demonstrated that the technological acceptance on the part of the medicine is immense which led to realize that, not only at the level of Parkinson but to other levels of diseases with dementia that are accompanied in the CNS, the technological need of tools for a better understanding of these conditions is huge.

Not only the introductory analyses but also the final questionnaires and the discussions about the proposed solution indicated new types of problems and new ideas for necessary solutions, opening new avenues for many more questions and research in this field.

Before developing Datapark, an analysis of which tools are being used and at what cost was made in the literature review, this guided me in the direction of developing a web platform to support clinicians in the clinical context because in the area there were a considerable number of devices with validated algorithms to evaluate movements of people with Parkinson's. However, the interfaces did not exist necessary to be used by people who are not naturally accustomed to working with signal processing software or more technical software.

While developing Datapark we included an evaluation with, traditional exercises of physical evaluation of Parkinsonians, the personalized new exercises that are done at the level of the CNS. We also included the use, to objectively evaluate these exercises, of a low cost inertial sensor and a mobile application that guides the clinician through consultations aimed at removing reliance on traditional mechanisms such as paper reports and stop-watches, storing the non-objective information the clinician needs to collect.

With that being said, the result of this project is a platform that can be used by any entities that want to physically evaluate people with Parkinson's or dementia-related diseases whose functioning is active and available for use in long-term studies since it has a reduced amount of errors, it has a broad set of benefits in relation to the limitations of traditional practices.

Analysing the goals, initially expectations, work accomplished and the conclusions drawn from the studies, it is possible to define a list of benefits and another one of limitations of this solution, as well as leave a set of suggestions for future work.

6.1 Benefits

The benefits of this project were in accordance with research questions, studies done and discussions with clinicians, which gives me a notion of accomplished goal. Therefore, after the studies carried out in a clinical context without observation, the importance of a platform of support for clinicians and how it benefits in the monitoring of patients by physiotherapists and other clinicians and how it facilitates the evaluation of the patients is shown.

In this way, Datapark benefits both clinicians and patients by supporting them in the following fields:

- Eliminates the need for paper and time control using stopwatch during clinical evaluations;
- It allows users to have simple and consistent reports of patient clinical performances, easily accessible;
- It combines in a single report the data traditionally used and subjective annotated by clinicians and the objective data obtained by algorithmic application of previously validated formulas and methods;
- The ability to obtain objective and reliable values for comparison using a low-cost accelerometer;
- Overall we combine in a single platform all patients information from clinical and free-living contexts, giving clinicians a central point to observe the advance or recess of Parkinson's in their patients.

Although the studies were too short to be able to see the progress of patients' health status, the insertion of this platform has brought them some instant benefits as well:

- For patients, it is important that their evaluation are made using smaller devices instead of large technological compounds that can cause some discomfort;
- The insertion of new technologies and new studies in the area of dementia has made the will to *"try new tools to cure a disease currently without cure"* motivating the patients and making our solution be extremely well received and a factor for many patients to strive and do their best in their evaluations;

Lastly, it is important to note that, according to clinicians, using the mobile phone did not affect the execution time and data collection of the evaluations but if the system was in full use and not only for study so that there is no need to store in the models of the CNS data, consultation time would be greatly reduced and would increase the availability for discussion and patient care.

6.2 Limitations

Unfortunately, some of the goals of the Datapark were not possible to prove. One of the objectives was to understand the impact of the platform in long-term Parkinson treatment, however, this was not possible due to the length of the studies weren't long enough to verify this evolution.

Another point that I would like to have fulfilled and was not able to validate was new algorithms to physically evaluate patients in clinical context exercises. Therefore, this will be a focal point for future work since now with a stable platform to manage patients and their evaluations, I can start the addition of new exercises and new algorithms to obtain objective data from both the new and the exercises already known.

Finally, one of the limitations had to do with problems at the level of the bracelets where several were damaged due to or not due to contact with water or other reason, which led to some data being lost during the execution of this project.

6.3 Future Work

Notwithstanding the number of tools already implemented in the system, Datapark has the potential to enrich with much more features, improvements and changes:

- Currently, Datapark is limited to the exercises presented in the previous chapters, however, a major improvement to this platform is the addition of new exercises and even let clinicians create custom ones. This is an idea that could led to new outcomes like new validated exercises and, therefore, new metrics and objective measures;
- One of the requests from the users was to improve the presentation of the reports, which had already undergone changes from one study to another, but which should continue to improve their quality in order to provide an immediate, optimal and pleasant interpretation;
- A significant improvement is the possible comparison of two reports on the platform, without the user having to open or print two separate reports and check the differences, and on the same screen can present a different model where older evaluations can be compared to see more clearly the progress of the disease;

- One of the problems that most disrupted the longitudinal study was the existence of some crash in the mobile application in the execution of the balance sheet evaluation exercise which was improved but in some cases still fails and for a more extensive use there should be this problem;
- At the moment, only one signal can be used for an Android report, however the same patient may have been evaluated with multiple sensors to detect values from different locations of the body which leads to the idea of producing reports that involve information from all sensors used at the same time and not just one. (Continuing to advise the use of the sensor on the trunk to obtain validated and reliable data);
- As argued in the limitations of this thesis, one of the possible future works in this project would be the addition and validation of new algorithms to evaluate the exercises;
- Addition of new data types collected during consultation of reports in electronic format, i.e., Audio, Video and annotations related to the exercises;
- In addition to the notes that clinicians can add to reports during clinical evaluations from the android application, it would also be interesting to allow the creation of notes for report elements in their final state allowing clinicians to identify some key points of the evaluation.

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Appendix A

Clinician Guide

PARKINSON CAMPUS

César Mendes, Diogo Branco, Tiago Guerreiro,
Faculdade de Ciências da Universidade de Lisboa

APLICAÇÃO MÓVEL (ANDROID)

PASSO 1: Antes de instalar a aplicação, no telemóvel onde se vai instalar ir a:

Definições -> Definições Avançadas -> Segurança **OU** Definições -> Segurança e activar **"Fontes Desconhecidas"**

PASSO 2: Ir ao Email (pelo telemóvel) e fazer download do ficheiro "DataPark.apk" que está em anexo.

(O telemóvel irá instalar a aplicação automaticamente e a partir daí basta utilizar a aplicação "PD_Activity_Lab" presente no telemóvel).

APLICAÇÃO WEB (SITE)

Página Inicial: Clicar em "Log In" e inserir credenciais de log in para entrar na aplicação.

Escolher paciente atual: Em qualquer momento o paciente atual é o que aparece no canto superior direito, para mudar basta carregar no mesmo, o que vai abrir uma lista de pacientes e escolher qual o paciente que se quer avaliar / trabalhar de seguida.

Adicionar novos pacientes: Ao entrar na página inicial da aplicação ou para ir lá ter basta clicar no nome do paciente atual e será redirecionado para lá, clicar em **"Create New Patient"**, inserir os campos necessários, clicar em **"Create"** e um novo paciente foi adicionado ao sistema.

Fazer upload de um ficheiro free-living: Clicar em **"Free-Living"** no menu superior esquerdo, de seguida clicar em **"Upload New File"** para abrir o menu de upload, onde basta colocar os dados da avaliação e fazer upload do ficheiro Axivity (.cwa) correspondente.

Fazer upload de um ficheiro de análise de laboratório: Clicar em **"Clinical"** no menu superior esquerdo, de seguida clicar em **"Upload New File"** para abrir o menu de upload, onde basta colocar os dados da avaliação fazer upload do ficheiro Axivity (.cwa) correspondente e **escolher a análise correspondente na lista de análises**

CONTA UTILIZADOR

Utilizador: Password:

URL (DATAPARK)

<https://parkinsondeploy.appspot.com/parkinson/>

Appendix B

Longitudinal Study Interview

Questionário aos clínicos do estudo longitudinal do DataPark

Este questionário é elaborado no âmbito de uma tese de mestrado da Faculdade de Ciências da Universidade de Lisboa. Tem como objectivo recolher a sua opinião sobre a utilização da plataforma DataPark.

O DataPark é composto por duas vertentes: avaliação clínica e avaliação funcional. A plataforma divide-se numa aplicação móvel, para apoio às avaliações clínicas, e uma aplicação web, para visualização dos dados e geração de relatórios.

Este estudo decorre de uma colaboração com o CNS (Campus Neurológico Sénior) e tem como principal foco uma avaliação preliminar do uso do DataPark no apoio dos clínicos no decorrer das suas funções e lhes permitir ter acesso a mais dados sobre os seus pacientes quer em avaliação clínica quer em avaliação funcional

O questionário será breve, agradecemos uma resposta criteriosa a todas as questões propostas.

Obrigado.

*Obrigatório

1. Endereço de email *

Informações Pessoais

Informação biográfica sobre o clínico.

2. Nome: *

3. Idade: *

Marcar apenas uma oval.

- Menos de 30
- 30-40
- 41-50
- 51-60
- 61-70
- Mais de 70

4. Sexo: *

Marcar apenas uma oval.

- Masculino
- Feminino

5. Profissão *

Marcar apenas uma oval.

- Fisioterapeuta
- Enfermeiro
- Outra: _____

Pacientes

Informação de contexto sobre os pacientes que tiveram contacto com o clínico.

6. Quantos pacientes foram avaliados por si em contexto de avaliação clínica com sensores? *

*

7. Quantos pacientes foram avaliados por si em contexto de avaliação funcional com sensores? *

8. Existiram alterações na forma como lida com o paciente pelo uso de sensores ? *

9. Existiram alterações no paciente pelo uso sensores? *

Caracterização da Aplicação móvel

Aplicação usada nas avaliações clínicas aos pacientes.

10. Teve algum contacto com o DataPark versão aplicação móvel? *

Marcar apenas uma oval.

Sim Passe para a pergunta 10.

Não Passe para a pergunta 17.

Caracterização da Aplicação móvel

Aplicação usada nas avaliações clínicas aos pacientes.

11. O uso da aplicação influenciou o tempo de execução das tarefas? *

Marcar apenas uma oval.

1 2 3 4 5

Pouco Muito

12. Durante a avaliação de que forma a aplicação influenciou o cuidado a ter com os pacientes

*

Marcar apenas uma oval.

	1	2	3	4	5	
Pouco	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Muito

13. Como classifica o tempo de aprendizagem para a aplicação? *

Marcar apenas uma oval.

	1	2	3	4	5	
Pouco	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Muito

14. Qual o grau de dificuldade sentido ao lidar com aplicação? *

Marcar apenas uma oval.

	1	2	3	4	5	
Reduzido	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Elevado

15. Quais os maiores problemas/dificuldades que sentiu ao usar a aplicação móvel? *

16. Como classifica o impacto que a aplicação tem durante a realização das avaliações clínicas? *

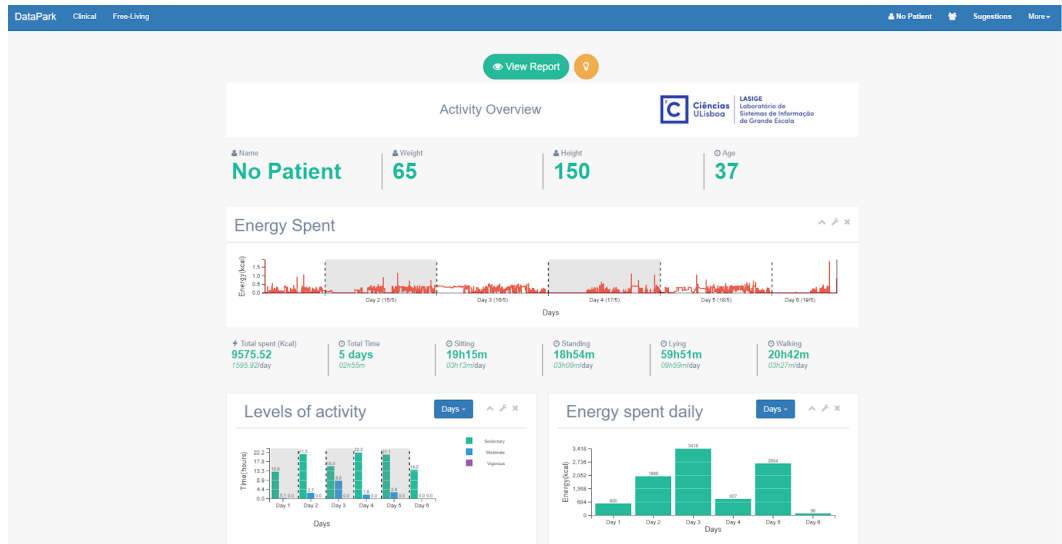
Marcar apenas uma oval.

	1	2	3	4	5	
Reduzido	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Elevado

17. Se desejar acrescentar mais alguma informação sobre o tema por favor indique-nos aqui

Caracterização da Aplicação web

Aplicação usada para visualização dos dados e geração de relatórios.



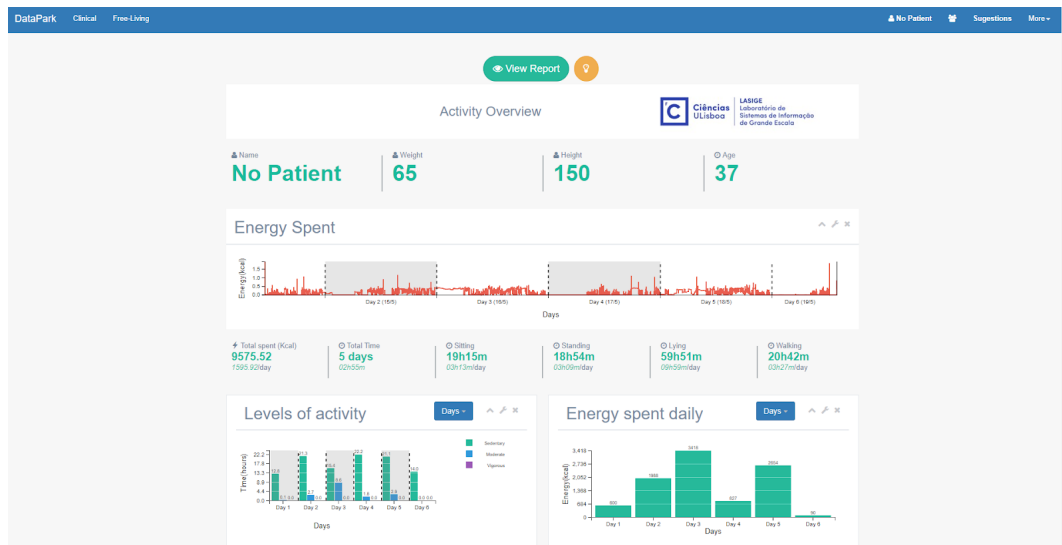
18. Teve algum contacto com o DataPark versão aplicação web? *

Marcar apenas uma oval.

- Não Passe para a pergunta 24.
- Sim Passe para a pergunta 18.

Caracterização da Aplicação web

Aplicação usada para visualização dos dados e geração de relatórios.



19. O uso da aplicação web influenciou o tempo de execução das tarefas? *

Marcar apenas uma oval.

- 1 2 3 4 5
- Pouco Muito

20. Como classifica o tempo de aprendizagem para a aplicação web? *

Marcar apenas uma oval.

	1	2	3	4	5	
Pouco	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Muito

21. Qual o grau de dificuldade sentido ao lidar com aplicação web? *

Marcar apenas uma oval.

	1	2	3	4	5	
Reduzido	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Elevado

22. Quais os maiores problemas/dificuldades que sentiu ao usar a aplicação web? *

23. Como classifica o impacto que a aplicação web teve para a posterior análise dos dados do paciente? *

Marcar apenas uma oval.

	1	2	3	4	5	
Reduzido	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Elevado

24. Se desejar acrescentar mais alguma informação sobre o tema por favor indique-nos aqui

Caracterização dos relatórios de avaliação clínica

Informação sobre os relatórios de avaliação clínica.



25. Teve algum contacto com os relatórios produzidos pelo Datapark em avaliação clínica? *

Marcar apenas uma oval.

- Sim Passe para a pergunta 25.
- Não Passe para a pergunta 31.

Caracterização dos relatórios de avaliação clínica

Informação sobre os relatórios de avaliação clínica.



26. A nível de compreensão dos relatórios considera-os de: *
 Marcar apenas uma oval.

1 2 3 4 5

Fácil Díficil

27. Os relatórios foram discutidos com os pacientes? *
 Marcar apenas uma oval.

Sim
 Não

28. Qual foi a reacção e comentários dos pacientes aos relatórios? *

29. Considera que os dados recolhidos em avaliação clínica contribuem para um melhor conhecimento sobre o paciente? *

Marcar apenas uma oval.

Sim

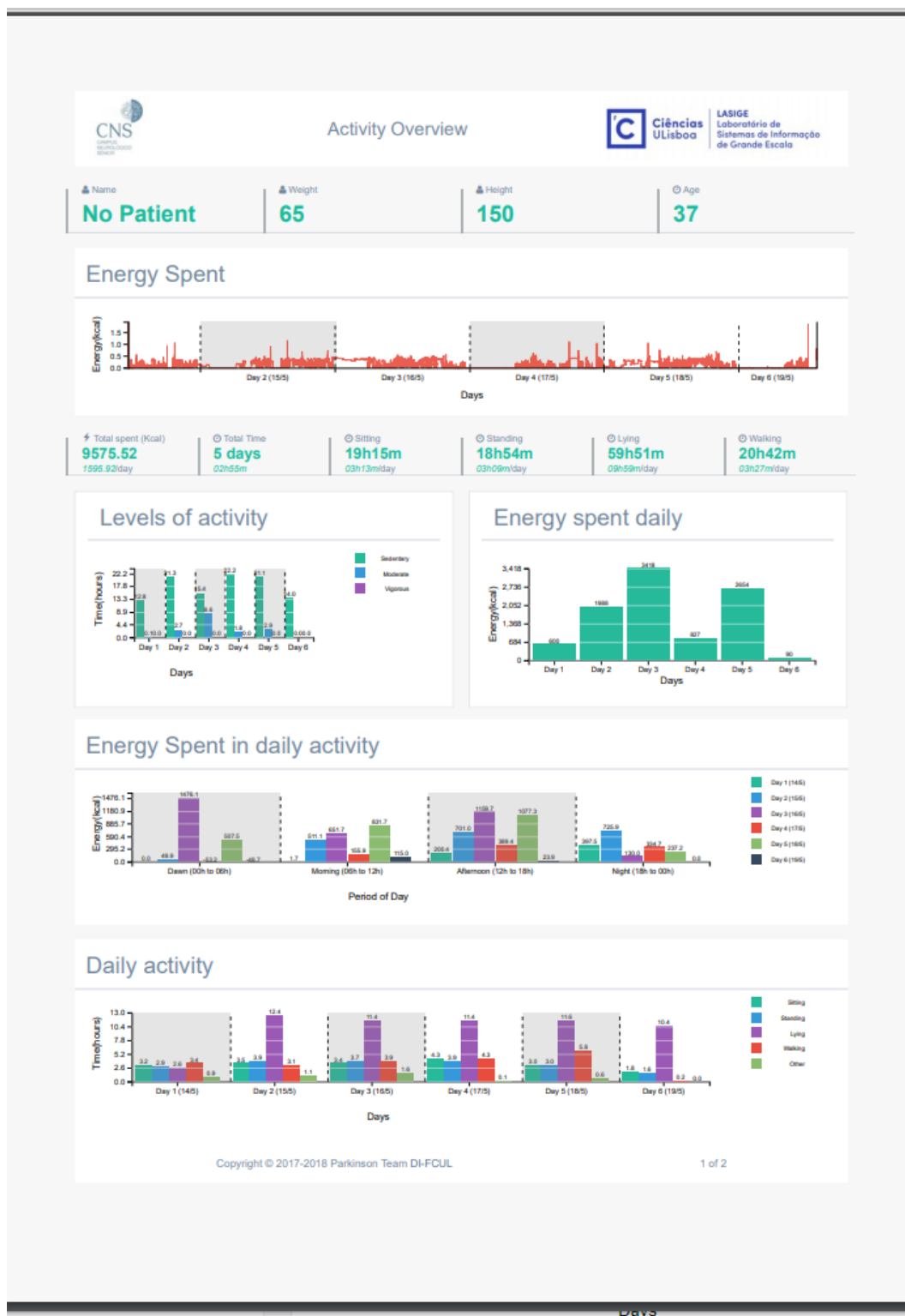
Não

30. Que tipo de informação achou mais útil nos relatórios? *

31. Se desejar acrescentar mais alguma informação sobre o tema por favor indique-nos aqui

Caracterização dos relatórios de avaliação funcional

Informação sobre os relatórios de avaliação funcional.



32. Teve algum contacto com os relatórios produzidos pelo Datapark em avaliação funcional?

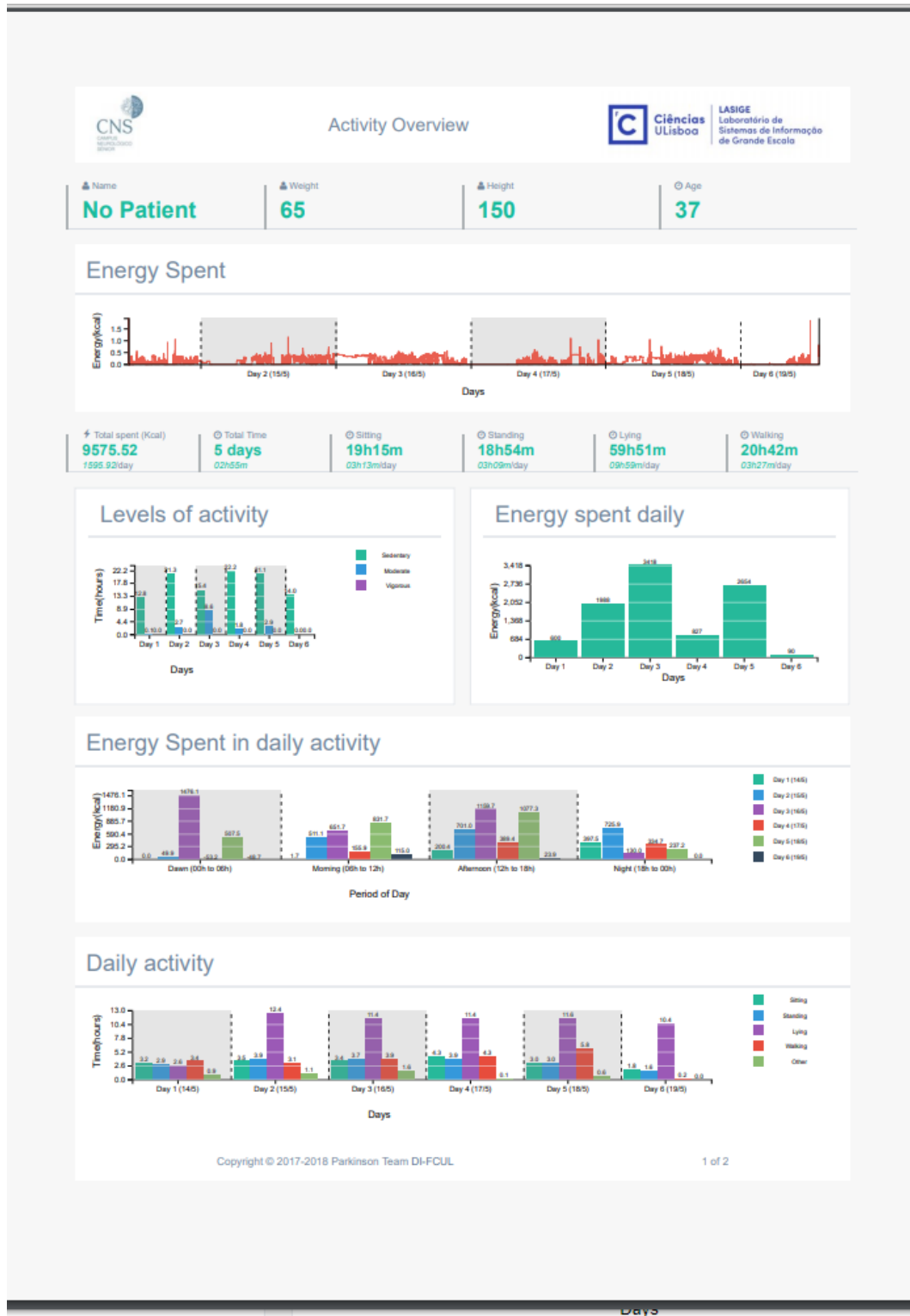
*

Marcar apenas uma oval.

- Sim Passe para a pergunta 32.
- Não Passe para a pergunta 38.

Caracterização dos relatórios de avaliação funcional

Informação sobre os relatórios de avaliação funcional.



33. A nível de compreensão dos relatórios considera-os de: *
 Marcar apenas uma oval.

1 2 3 4 5

Fácil Díficil

34. Os relatórios foram discutidos com os pacientes? *

Marcar apenas uma oval.

Sim

Não

35. Qual foi a reacção e comentários dos pacientes aos relatórios? *

36. Considera que os dados recolhidos em avaliação funcional contribuem para um melhor conhecimento sobre o estado do paciente fora do ambiente clínico? *

Marcar apenas uma oval.

Sim

Não

37. Que tipo de informação achou mais útil nos relatórios? *

38. Se desejar acrescentar mais alguma informação sobre o tema por favor indique-nos aqui

Funcionalidades DataPark

Informação sobre as diferentes funcionalidades do DataPark e que impacto tiveram para os clínicos

39. Na sua opinião quais os aspectos negativos que os dados obtidos pelo sensor trazem na avaliação do paciente? *

40. Na sua opinião quais os aspectos positivos que os dados obtidos pelo sensor trazem na avaliação do paciente? *

41. Classifique as funcionalidades do DataPark de acordo com as que considera mais e menos importantes *

Escolha NA quando não tiver opinião formada sobre alguma das funcionalidades
 Marcar apenas uma oval por linha.

	NA	Pouco Útil	Útil	Muito Útil
Aplicação móvel	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Exportar relatório para PDF	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Exportar gráficos como imagem	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Visualização na plataforma do relatório	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Adicionar filtros aos dados	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Construir o próprio relatório	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Processo de Registo dos Utilizadores	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Caixa de Sugestões	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

42. Se desejar acrescentar mais alguma informação sobre o tema por favor indique-nos aqui

Pretendo receber uma cópia das minhas respostas.