Literature study of eHealth solutions for treatment of Parkinson's disease

SSY115 - Health Informatics

Group 3

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May 24, 2021

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Abstract

Parkinson's disease (PD) is the second most common disorder affecting the nervous system. Worldwide, up to 10 million people are estimated to be diagnosed with PD [1] and the disease can therefore be considered a global health issue. Today there is no cure to stop the progression of the disease. It is therefore motivated to continue the study of PD and develop several solutions aiding people diagnosed with the disease. The most prominent symptom of PD is the degeneration of motor functions but there are also non-motor related effects. Since every person experiences different symptoms, it is necessary to provide a diverse set of treatments. The increased usage of smart devices provides a possibility of developing digital patient-centered solutions aimed to be used at home. This literature study presents various digital solutions for an efficient monitoring of different symptoms experienced by persons diagnosed with Parkinson's disease. Solutions are presented for each of the four motor related symptoms described by the TRAP acronym (Tremors, Rigidity, Akinesia - slowness of movement, Posture). Further, an additional solution based on a mHealth platform and a solution related to telemedicine are discussed. A comparative study of all above solutions is presented, resulting in the conclusion that many solutions are aimed for motor related symptoms but there is a lack of methods providing treatment for non-motor related symptoms. Lastly, it was concluded that there is great potential for a future use of digital solutions for Parkinson's disease.

Keywords: Parkinson's disease (PD), TRAP, eHealth, mHealth, Telemedicine, Neurodegenerative disorder

Contents

List of Abbreviations

AR Augmented Reality

BAN Body Area Network

DBS Deep Brain Stimulation

EMG Electromyography

EPDA European Parkinson's Disease Association

FOG Freezing of Gait - a possible motor symptom of PD.

HP Healthy Patients

mHealth mobile health - medical solutions based on the use of mobile devices

ML Machine Learning

PD Parkinson's disease

PDP Person(s) diagnosed with Parkinson's disease

PIGD Postural Instability and Gait Difficulty

TRAP Tremor - Rigidity - Akinesia - Posture. Categories of motor symptoms in Parkinson's disease

1 Introduction

The following section provides a theoretical background describing Parkinson's disease. This information is necessary to follow the later presented and discussed digital solutions aimed to aid people diagnosed with the disease. Finally, the aims and limitations of the study are declared.

1.1 Background

Parkinson's disease (PD) is estimated to be the second most common disorder affecting the nervous system (i.e. the nerves and the brain) [1], [2]. Around 3% of the population in Europe has been diagnosed with the disease and $60,000$ new cases are detected each year in the U.S. [2]. As of today, around 7-10 million people worldwide are diagnosed with PD and this number is expected to increase dramatically over the coming two decades, as the global life expectancy is getting higher [1], [2]. Currently, there is no treatment available to reverse the progression of PD but measures can be taken to ease the severity of the symptoms as experienced by the patients.

As mentioned above, PD is a disease which affects the nervous system. In addition to other jobs, this system is responsible for assisting with both voluntary and involuntary movements of the whole body. The neurons (nerve cells) acting as messengers in a human body produces a chemical substance called dopamine [3]. For a person with PD, a transition occurs such that the neurons either die or get impaired which leads to a decrease in the dopamine production. As a result, a person with previously normal movement begins to experience mild symptoms of irregular movements, imbalance and slurry speech. As the reduction factor of dopamine keeps increasing over time, the severity of the symptoms also increases. This results in a loss of nerve endings which at a later stage leads to abnormal motor skills, as well as a possibility of an increased stress level and irregular blood pressure. The loss of neurons is one of the main contributing factors to the onset of Parkinson's disease and scientists are underway to find the root cause for this process [3].

The early-onset of Parkinson's disease is usually identified from symptoms like shaking (tremor), stiffness (mostly prevalent in the dominant hand) or slowness of movement. The symptoms gradually worsens over time leading to difficulty with balance and the coordination of motor skills [4]. At an early stage, the patient's face may show very little to no expression, the involuntary arm swing while walking might not be visible and changes in speech tone and texture can occur. As the disease progresses, a patient may have difficulty to integrate with all the skills required for a normal routine to live a healthy life. To get a better view of the onset of disease along with its symptoms detected at various stages and the severity level, figure 1 holds good. Despite the fact that the cause of PD is unknown, some factors such as age and stress, family history along with environmental toxins (with particular focus to pesticides and drug abuses) are deemed to be responsible to promote the disease [4], [5]. Studies show that PD is known to affect irrespective of gender. Surprisingly, statistical data shows that the disease is likely to affect men 50% more than women [3], [4].

There are several symptoms related to PD. The most prominent symptoms are motor related but there are also cognitive and behavioural changes as well as autonomic system failures [2]. Common non-motor symptoms experienced by persons diagnosed with PD are sensory, sleep and mood disturbances. The motor related symptoms are often described by the TRAP acronym, where T stands for tremors, R for rigidity (stiffness), A for akinesia (slowness of movement) and P for postural instability [2]. These are often what first leads a person to seek care for PD. Since different people experience different symptoms, the treatment has to be highly individualized. There are several measures to be taken in order to ease the severity of the symptoms. Both pharmacological and non-pharmacological approaches, such as exercise, education, nutrition and support group speech therapy can be taken [2]. In rare and very specific cases, it is also possible to take surgical therapies into consideration. These include deep brain stimulation (DBS) leading to a decrease of the ability of dopaminergic neurons to absorb dopamine [2], [3].

Since the complication of the disease is high, multidisciplinary management of the disease involving several professionals (neurologist, psychologists, physiotherapists, speech and language therapists, occupational therapists, dietitians etc.) are recommended for the self being of the patient. It is highly inconvenient for a patient to visit a hospital on a daily basis (especially during the last year with the COVID-19 pandemic) for a consultation with a doctor. Hence, the usage of various eHealth solutions could play a major role here. Using such digital solutions, it is possible for the involved doctors to monitor and assess the severity of some symptoms for persons with Parkinson's disease without the need of an in-person meeting. Upon diagnosis, it makes it less stressful for the doctors to offer dedicated nutrition, physiotherapy and certain educational videos. Few eHealth solutions embed with the latest technologies available on market while few have inbuilt applications like medication reminders, latest articles and research trends, discussion forums and attractive games like finger tapping, ball bouncing, etc..., that helps patients to aid with their memory loss and assist with daily living [6].

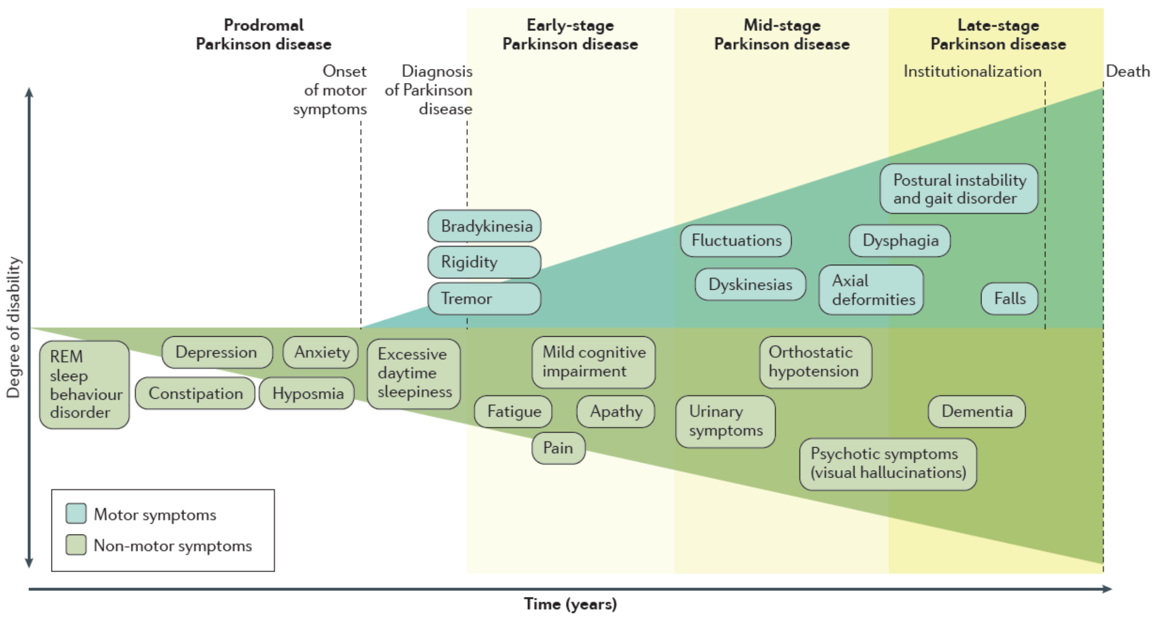


Figure 1: Motor and non-motor symptoms related to Parkinson's Disease [4].

1.2 Aims

The overall aim of this literature study is to provide information of several digital solutions aimed to facilitate everyday life for people diagnosed with Parkinson's disease. Here, digital solutions refer to eHealth, mHealth or telemedicine. Below follows a list specifying the aims of the work.

1. Identify possible digital solutions related to monitoring and treatment of Parkinson's disease
2. Identify pros and cons with the solutions in aim 1.
3. Make a comparative analysis of the solutions in aim 1 based on the findings in aim 2.
4. Identify what is missing regarding digital solutions based on all above aims.

1.3 Limitations

Parkinson's disease is a well studied phenomena but there is a lot that is not yet understood. Thus, there is much information available on the subject and some limitations for this project has therefore been formulated. First of all, only a brief description of the disease and its consequences is presented since there are many reviews and sources including this information already available (see e.g. reference [7], [8] and [9]). Further, only solutions for people with mid-stage PD has been considered. This is partly to enable a sufficient analysis, partly since many state-of-the-art digital solutions focus on this phase of the disease. Here, mid-stage PD is stage 3 PD as defined by The Hoehn and Yahr scale [10]. Thus, this study is focused on patients possibly experiencing tremors, slowness of movement and imbalance as well as speech impairment and difficulties in facial expressions. Finally, the presented solutions are aimed to display a variety in treatment methods both regarding covered symptoms and technical approach.

2 Methods

In order to fulfill the aims presented in section 1.2 a literature study was performed. Initially, a general search through various scientific databases, namely PubMed, IEEE, Science Direct, Google Scholar and Chalmers University of Technology Library was made. In this phase, the used search terms were some combination of *'Parkinson disease'* and at least one of the following keywords: *'treatment'*, *'digital solution'*, *'review'*, *'eHealth'*, *'mHealth'* and/or *'embedded systems'*. This resulted in a large amount of articles, which were critically analyzed to enable a careful selection of studies to investigate further. The selected texts provided an introductory understanding of the disease and the current state-of-the-art regarding innovative solutions in this area.

To further fulfill aim 1-4 from section 1.2 the knowledge gained from the above procedure was used to make a more specific search through the previously mentioned databases. In this phase, keywords such as *'Quantification of rigidity in PD'*, *'Treatment of tremors PD'*, *'TRAP treatment'* and *'Sensors for measuring akinesia OR tremors'* were used. Since eHealth has been a fast developing technology during the last decade [11], only more recent (later than 2013) studies were included in the selection of potentially interesting articles. Following the limitation regarding only presenting solutions for mid-stage PD, as presented in section 1.3, studies describing methods and technologies for an early-detection and/or diagnosis of PD were excluded. For a better understanding, a pictorial representation of the article selection process is given in figure 2.

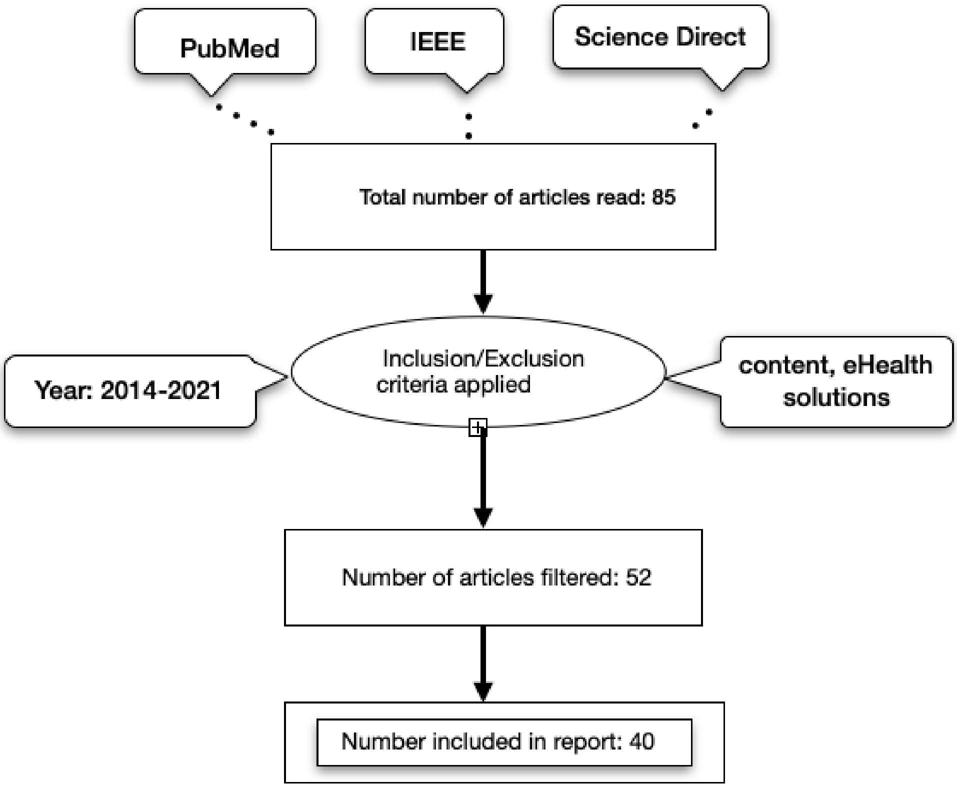


Figure 2: Overview of the selection process of the articles.

Moreover, to get a broader understanding of the topic and the currently available mHealth solutions, several mobile applications have been downloaded and briefly tested. The tested apps were "CYPD", "Point of Care", "Parkinson's Rehab", "PD warrior", "Peak", "uMotif", "Word or Color (Stroop Test)", "Beneufit" and "FonateDAF - Stuttering help". These were all aimed to aid in the physiotherapy and help a person diagnosed with PD to cope-up with the disease.

3 Results

The following section presents six patient-centered solutions based on eHealth, mHealth or telemedicine, for a facilitated tracking and monitoring of the symptoms experienced by persons diagnosed with Parkinson's disease (PDP). As previously mentioned in section 1, common symptoms of PD are mainly motor impairments. However, there are also symptoms which are not related to motor functions, such as sleep deprivation, speech impediments and hyposmia (i.e. the impairment of the sense of smell) [12]. Thus, various solutions covering different types of symptoms might be needed to fully monitor the progress of the disease. This motivates the selection of the solutions presented in section 3.1-3.6. Initially, four eHealth solutions based on the TRAP mnemonic (i.e. covering motor impairment) are presented, followed by a description of a mHealth solution aimed to monitor both motor and non-motor related symptoms along with an analysis of the effects of the ongoing pandemic caused by the virus SARS Cov-2 on Parkison's disease patients. The symptoms which each solution covers is also summarized in table 1 below.

Table 1: Summary of which symptoms are covered by which solution.

	Symptom	Technique
Solution 1	Tremor & Akinesia (slowness of movement) - T & A	eHealth
Solution 2	Rigidity - R	eHealth
Solution 3	Postural instability (imbalance) - P Inability to balance	eHealth
Solution 4	Freezing of Gait (FOG)	eHealth
Solution 5	mHealth platform	mHealth
Solution 6	Role of Telemedicine during COVID-19 Pandemic	Telemedicine

3.1 Solution 1: A wrist-worn wearable device for tracking resting tremor and slowness of movement

A person cannot be diagnosed with PD without experiencing an increased slowness of movement. Further, one of the most common symptoms experienced by persons seeking care for PD is hand tremors [13]. Thus, tracking both tremors (the T in TRAP) and such movements (the A in TRAP) is significant for monitoring the progress of the disease for many persons with PD. A common solution for tracking some sort of movement is the use of sensors. In particular, accelerometers and gyroscopes are commonly used in devices related to PD. An accelerometer can only be used to monitor a change of speed, while a gyroscope can be used to detect a change of both speed and direction [14]. However, while the latter is more accurate it is also more computationally expensive and a wearable device comprising this does therefore require a larger battery [12].

One example of a digital solution for the tracking of resting tremors and slowness of movement is presented in a recent study (published 2020), describing a wrist-worn wearable device aimed for individual at-home usage [12]. An illustration of such a setup is presented in figure 3. The device is a body area network (BAN) based on an accelerometer and machine learning (ML) techniques aimed to identify the presence of tremors and/or slowness of movement in a patient diagnosed with PD. To enable such an identification, data was collected from 60 healthy persons (HP) and 35 persons diagnosed with PD. This was achieved by letting the device identify the presence of the relevant symptoms. These measurements were later compared to a clinical rating performed by experienced examiners. The comparison demonstrated a sufficient compliance between the two methods. On the contrary, a distinction was observed between the severity of the symptoms reported by the device and the severity reported in the form of a self-evaluation by the trial persons. It was therefore concluded in the study that the device could perform equally

Figure 3: Example of a wrist-worn wearable single sensor device aimed for at-home usage [15].

well as a clinical evaluation and prevent the presence of a bias as introduced during a self-evaluation process.

In addition to the analysis of the performance in detecting the relevant symptoms, the ease of use of the device was analysed. It was concluded that a single sensor was preferred over multiple ones and that a slight decrease in sensitivity was preferred over a larger battery (which as previously mentioned would be a result of a more power consuming device). Based on this and a rating performed by the trial persons regarding the user-friendliness, the overall ease of use was in the study concluded to be sufficient [12].

Beyond scientific studies, there are also wrist-worn wearable devices aimed to monitor tremors, available on the market today [16]. One example of such a device is Cala Trio, which is shown in figure 4. This is a bracelet comprising of an accelerometer, aimed to measure the occurrence of a patient's tremors. In addition to solely monitor the shaking, it can also be used as a non-invasive treatment method. Independent studies have concluded Cala Trio to be an efficient device both for tracking and treating tremors [17]. The user-friendliness has further been determined to be sufficient, mostly due to it being light-weight and only comprising a single sensor [18].

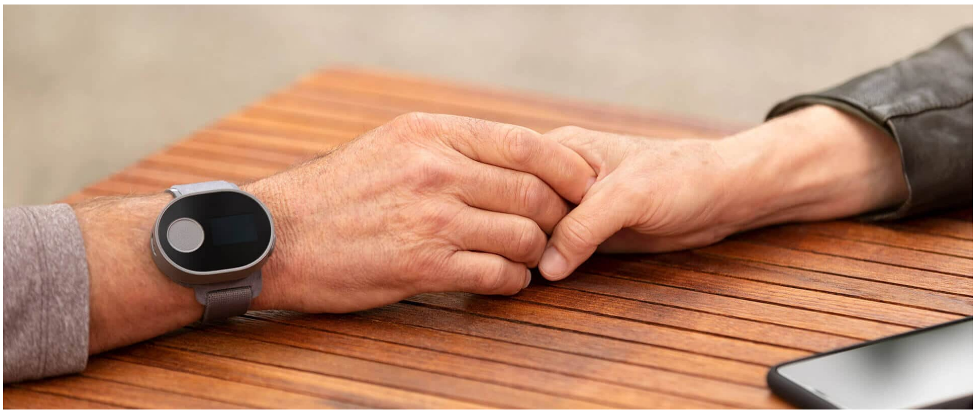


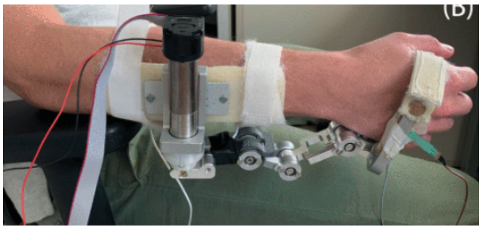
Figure 4: A wrist-worn wearable device aimed to monitor tremors, provided by Cala Health and available on the market today [16].

3.2 Solution 2: Quantitative measurement of rigidity in Parkinson's disease.

Out of the four cardinal motor symptoms (TRAP), it is estimated that up to 89% of patients diagnosed with Parkinson's disease are prone to experience rigidity [19]. In medical terms rigidity can be referred to as muscle stiffness or resistance to passive movement typically assessed and compared against clinical scales.

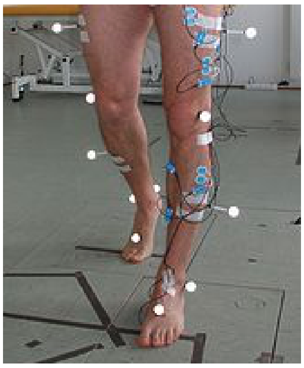
Several teams of biomedical engineers and researchers belonging to neurology units came up with different ideas to measure this rigidity factor quantitatively so as to enable self-assessment at home in a convenient manner. Throughout the case studies, rigidity was assessed using sensors, motors and biomechanical and neurophysiological study of muscles. According to sources used in all the case studies included in this solution it showed good reliability, good correlation with clinical scales and were useful for studying its evolution.

Table 2 showcases a comparative study of the quantitative measurement of rigidity factor that was assessed between Parkinson's disease (PD) patients and healthy subjects. The table provides an overview of on what physical conditions the trials were conducted with the end results obtained. Further, an illustration of each of the presented devices are given in figure 5 to give an idea of their physical features worn during the flexion-extension movement during assessment as illustrated in figure 6.

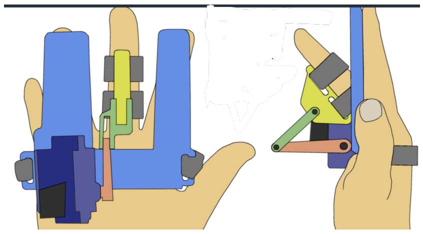


(a) PDMeter [20]

(b) NeuroFlexor [21]

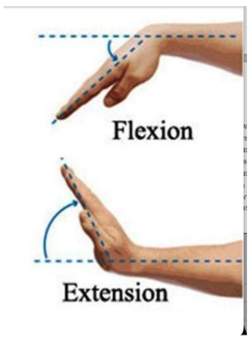


(c) Surface EMG electrodes at lower limb [19]

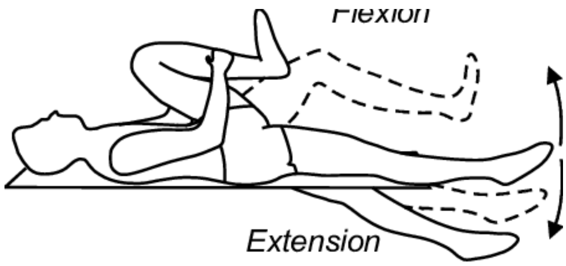


(d) BiRD [22]

Figure 5: Devices used to measure rigidity. Figure (a) belongs to case study 1, (b) to case study 2, (c) to case study 3 and (d) to case study 4.



(a) Arm flexion-extension [23]



(b) Hip-Knee flexion-extension [24]

Figure 6: Flexion-extension of upper and lower limb region

In table 2 the following statements holds good.
** - 1 Cycle here refers to a flexion along with an extension.*
*** - Quantitative measure of wrist stiffness factor.*

Table 2: Overview of case studies for quantitative measurement of rigidity.

Used to Measure	**Type of Movement**	**Number assessed for clinical trials**	**Condition examined**	**Results**
Case study 1 : PDMeter [20]				
Wrist stiffness	Arm flexion-extension with 5 repeated cycles*	7 PD, 14 healthy	Device fitted to right arm in relaxed state, • PD subjected examined twice with 1. PDoff - PD subjects on medication at highest efficacy. 2. PDon - PD subject on no medication.	$(K_E, K_F)^{**}_{PDon} >> (K_E, K_F)_{PDoff} >> (K_E, K_F)_H$
Case study 2: NeuroFlexor [21]				
Wrist stiffness	Arm flexion-extension with 5 slow stretches followed by 10 fast stretches	25 PD, 14 healthy	Device fitted to forearm and tested under following 2 conditions. • Dynamic - user at relaxed state. • Passive - device on one hand, while a movement given on the other hand.	End results coherent with the clinical scale.
Case study 3: Surface EMG [19]				
Lower limb rigidity (hip, knee & ankle)	Hip-thigh flexion-extension with 3 repeated movements	8 PD, 16 healthy	Sensors placed on hip, knee and thigh regions	Muscle stiffness at the hip, knee and ankle regions was at least with a mean measure of 1.5 times higher in PD patients than healthy persons.
Case study 4: BiRD [22]				
Finger stiffness	Finger flexion-extension with 15 continuous cycles.	25 PD, 22 healthy	Device placed at the base of the third finger. • Users asked to draw an imaginary circle in air with most affected as well as less affected hand with DBS device [25] in ON and OFF state but PD subjects stopped medication the night before.	Stiffness in Parkinson's patients gradually increased after the DBS device was turned off within an hour while stiffness was eased immediately when DBS was switched back to ON state. It can be concluded that DBS device eases the muscle rigidity.

3.3 Solution 3: Postural Instability in Parkinson's disease

As shown in figure 1, one of the last complications of late stage Parkinson's disease is postural instability and gait disorders (PIGD). This is defined as the inability of the patient to stand in an upright position [26]. As a consequence, a patient experiencing postural instability may easily fall backwards, which may lead to a fracture.

Postural instability is most prominent in a PD patient while standing upright or rising from a seated or lying position. This is one of the most stressing symptoms of Parkinson's disease, that greatly diminishes an individual's level of mobility. There are many clinical tests, assessment scales, bio and biomechanical markers, and gait predictability techniques available to diagnose and scale the level of postural instability. The most prominent among these is the pull test [27]. This is used to assess the potential of the patient to recover from a backward pull on the shoulders. The major task in a pull test is the evaluation of imposed backward pull. To support this pull test a wearable inertial modulus showed in figure 7b is placed on the patient's chest. This inertial unit has an accelerometer and gyroscopes, which measures the strength of the backward pull. Using that measurement, postural instability is assessed [28]. Instruments like force plates, as illustrated in figure 7a, are used to measure the pressure on the feet, which assists in standing [27].

(a) Force plate [27] **(b)** Wearable inertial modulus [28]

Figure 7: Example of a set-up of backward pull test [27], [28]

There are currently few possible way to prevent injuries from falling due to postural instability. A solution that possibly could be adopted consists of a wearable airbag jacket or vest, designed by a Chinese company named S-AIRBAG, to prevent elderly from falling [29]. The system detects the difference between normal and improper posture and avoids the potential risk of fall or any injuries to head and hip region, as shown in figure 8a and 8b respectively. The airbag is designed to act at a rapid way such that it is released within 0.18 of a second [29].

(a) Detection of the fall of the system [30] **(b)** Airbag opened after fall detection [30]

Figure 8: Wearable airbag jacket system [29],[30].

3.4 Solution 4: Wearable glasses aimed to reduce the occurrence of freezing of gait

In addition to the motor symptoms described by the TRAP acronym, there is yet another motor symptom called freezing of gait (FOG). This is defined as the absence or reduction of the feets' forward progression, despite the intention to walk. This sort of motor symptom can progress to daily occurrence level and is particularly prominent e.g. when initiating a gait, turning around a corner or standing up after having been seated. It has been shown that the FOG experienced by a PD patient can be considerably reduced by using some sort of visual or auditory cue. For instance, in 2017 Ahn et al. [31] developed a smart AR-based[1] visual guidance system in the form of wearable glasses, as showed in figure 9. The glasses are used to monitor the patient's walk to further enable a detection of FOG. If a FOG is detected, a visual pattern is projected on the glasses as shown in figure 10. The pattern consists of straight lines orthogonal to the direction of movement, experienced to be placed on the ground. This is to fool the eyes that the gait is continued instead of interrupted. The study of the developed system showed a remarkable improvement in the mobility and fastening the walking pace of the patient. Results showed that persons who tested the visual guided system displayed an increase in walking velocity of 32.1% and stride length of 24.0% compared to the case without [31].

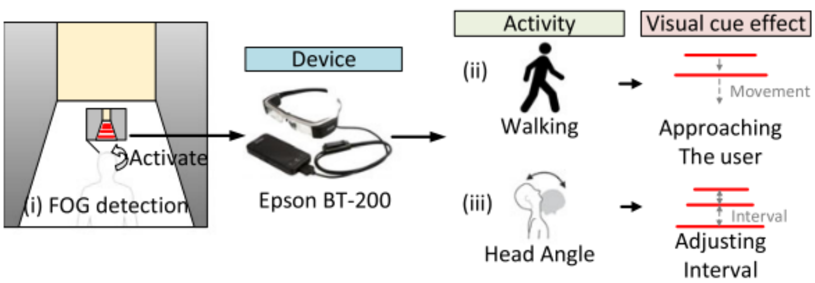


Figure 9: Smart gait-aid system based on FOG detection and movement recognition [31]

[1] AR is short for Augmented Reality

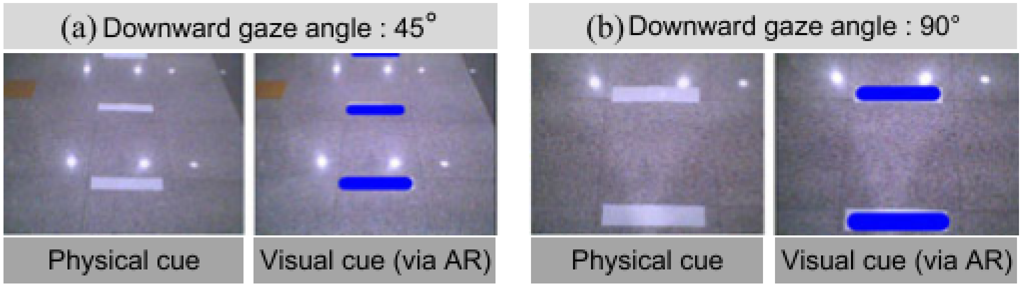


Figure 10: Comparison of real physical cues and virtual cues projected by the system [31]

3.5 Solution 5 : PD_Manager - a mHealth platform

People affected by PD might as previously mentioned, also experience non-motor symptoms. These can consist of psychiatric and cognitive alterations as well as neurovegetative symptoms, namely a progressive degeneration and loss of sensory and cognitive function [32]. To manage such symptoms, new holistic approaches have been studied during the last few years in order to have a comprehensive and complete view of the disease.

In 2015, a project called PD_Manager, based on mHealth was founded with the aim to create a multidisciplinary disease management. This was to involve the participation of several different professionals such as neurologists, physiotherapists, speech and language therapists, occupational therapists and dietitians. This was further in order to have an holistic and joint approach toward the disease that contemplate the management of both motor and non-motor symptoms [33]. Moreover, the main idea was to enable a patient-centered approach and have a cooperation between the clinicians in order to assure a better quality of life for the patient as showed in figure 11 [34].

Figure 11: The patient centered paradigm presented by PD_Manager [34]

The platform is based on the usage of mobile devices with the possibility of integrating wearable devices such as insoles or wristbands. The platform was further created to be easy-to-use. The wearable device acquires data such as measurement for distribution of pressure, acceleration, weight-bearing, balance, motion sequences, continuous heart rate, motion, skin temperature, and daily activity. The non-motor symptoms, such as anxiety, emotional state, cognitive status, speech disturbances and sleep disorder are updated on the app by the patient itself [34]. Continuous reports of the patient's current status are further sent by the platform to the clinicians to suggest possible changes of treatment, medication plan or management of new symptoms. Additionally, the platform is able to specify the patient adherence to the treatment, reporting to the clinician and motivating the patient to comply to the program. Furthermore, the patient will receive recommendations, change of the medication plan, diet, activity and physiotherapy through the app. Moreover, the platform is able to inform the caregivers of emergency alerts in case of the patient being in a critical situation, such as falling [33].

3.6 Solution 6: A special role of telemedicine in Parkinson's disease during the COVID-19 pandemic

In response to the COVID-19 pandemic, many clinics across the world closed their doors unexpectedly for many patients, including patients with Parkinson's disease. Fortunately, telemedicine led to a "fundamental restructuring" of both clinical care and trials. Telemedicine requires internet and video conferencing software tools between the patient and the care provider. These online tools provided the feasibility to visualize most of the core features of the disease except rigidity and postural reflex impairment through recorded sessions and video consultations [35]. The International Parkinson and Movement Disorder Society has implemented a step-by-step guide on how to implement telemedicine for movement disorders which includes list of providers according to specific regions. For more information about this, please refer to [36].

One interesting study related to the potential of using telemedicine for PD patients was conducted during last year. Due to the current pandemic and in particular during its peak in Italy, many patients experienced a lack of health care. 400 PD patients were therefore provided free phone consultations. Based on the degree of emergency, 100 patients were given subsequent online consultations with neurologist, therapists, etc... . The notable factor here is that over 60% of the patients provided a positive feedback [37].

At the early outbreak of the current COVID-19 pandemic in March 2020, the medical community worked united and assiduously in order to protect the vulnerable people in the society from the risk of getting COVID-19. As a result, since community-based rehabilitation was restricted, scientific papers and guidelines were adopted and spread throughout the community. As far as PD is concerned, a list of apps aimed for e-Rehabilitation was proposed to help patient to have a home-based and an out-patient rehabilitation [38].

In Table 3 below, an overview of the apps tested from a student is presented. There are mainly two types of apps, the ones designed to be PD-centric, namely monitoring symptoms, recommending exercises, reminding medication treatment etc., and on the contrary the others can be used by PD patients but they are not designed exclusively for them. The list of the apps was acquired from [38].

Table 3: Summary of the tested apps.

App name	OS	Description	Result
PD Warrior	Android	Rehabilitation app based on exercises and workout. Also network support, education channel, confidence booster and a motivational coach to keep consistency in the exercises.	PD Warriors showed that 94% of people continued exercising after the PD Warrior 10 Week Challenge had been completed and 98% of people thought that the program was worth their time [39].
Peak	Android	App based games to improve brain cognitive skills. Based on challenges, and quick tests to evaluate cognitive skills on timely basis that are based on neurological studies.This lead to affect brain functionality performance of other related tasks that haven't been the subject of training [40].	Exciting and interesting app. Not focused on PD but accessible to everyone. Challenging game, sometimes difficult even for the student during the test, it might be difficult for people with limited motor or cognitive skills. User-friendliness can be improved.
Fonate DAF - Stuttering Help	Android	App for speech impairment. It combines Delayed Auditory Feedback (DAF) and Frequency Altered Feedback (FAF) to reduce stuttering. As a result it reproduce the audio with a slight delay and a pitch change while speaking.	Very easy to use. Works Best when paired with headphone. Focused on only speech impairments. Chance to modify the settings based on own preferences.
uMotif	Android	A patient-centered app that keeps track of daily activities, symptoms, treatment, outcomes and experience [41].	Designed particularly on PD. Designed to be used to keep track of the disease over time.
Word or Color (Stroop test)	Android	Test brain activity to quickly process confusing or conflicting information in challenging games. Different sets of games and level of difficulty.	Challenging game. Easy to understand and user-friendly.
Point of Care	iOS	Mainly designed for users in US, but accessible also for users from other countries. Article based app with speech recognition and tracker for everyday activity where there is option to set goals. Required premium level for extra services. Possibility of a forum to connect with other users.	A general user may find it difficult initially to use.
Beneufit	iOS	Based on games, such as circle tap game divided in two levels that should be played with both hands, option to set own goals and targets. Medication reminders included. Game reminder. Possibility to pair sensors while doing exercise as well as of a forum to connect with other users.	User-friendly.

4 Discussion

This section will provide a thorough discussion of the digital solutions presented in section 3 in terms of covered symptoms and usability.

4.1 Analysis of solution 1

The overall usability of a wrist-worn wearable device as presented in section 3.1 was in the clinical study in ref. [12] concluded to be sufficient. This was mostly based on the simplicity of the sensor (as experienced by the trial persons) as well as its placement on the body. In the study it was reported that the users preferred to use a single sensor rather than several ones and that a lighter device with less accuracy, was preferred over the opposite. However, it can be argued that these results are not sufficient to conclude an overall adequate user-friendliness. It is to be expected that fewer, smaller and lighter sensors are preferred in devices aimed for everyday use. It is therefore necessary to compare the device to similar ones already in use, to conclude if it de facto is user-friendly.

For instance, to determine whether to use an accelerometer or a gyroscope, the trial persons in the study were asked if a smaller battery (as in an accelerometer) was preferred over a better accuracy (as in a gyroscope). However, it was nowhere mentioned that most smart watches already have a built-in gyroscope. A more accurate question could therefore have been if the trial persons would prefer a separate device which could only be used for the specific tracking (i.e. an accelerometer), or an embedded function in a smart watch (i.e. a gyroscope). To answer this, the question of affordability has to be discussed. Using a separate device solely aimed for tracking of symptoms related to PD would probably be less expensive than using a smart watch. However, if the patient already uses a smart watch, there is no need of buying an additional device. Further, this would probably increase the probability of the patient actually wanting to use the device.

In addition to the arguments presented above, the device Cala Trio (introduced in section 3.1) can be analyzed to get a better understanding of the practical implementation of a wrist-worn wearable device such as the one presented in the clinical study. Firstly, since the Cala Trio bracelet only uses an accelerometer and not a gyroscope it can be concluded that this provides sufficient accuracy. Further, since no information was found about the weight of any of these devices it is difficult to determine if a slightly heavier device would be equally as appreciated by the users. However, since both patients with PD and independent reviews concluded a sufficient efficiency and accuracy, the conclusion in this study is that an accelerometer should be used rather than a gyroscope. This is further strengthened by the fact that one of the main reasons why the Cala Trio device was determined to be user-friendly is because of it being very light-weighted.

4.2 Analysis of solution 2

The end results obtained with all the devices for measurement of rigidity factor were coherent with the clinical scale. While devices like PDMeter and NeuroFlexor proved that they could serve as a useful biomarker for rigidity they also required to always be assessed in a manual environment. Findings from NeuroFlexor could not be validated due to the lack of EMG measurements, but demonstrated that 'neural component' was one of the contribution factor to rigidity. Future studies of PDMeter include higher samples of PD patients and assessment in unstructured environments. Research work is underway for BiRD to enable self-assessment at home similar to a blood-glucose monitor for diabetics for it's relatively small size and easy handling but case studies related to this are yet to be validated.

As the famous saying goes "An ounce of prevention is worth a pound of cure.", it also binds well as one of the aiding factor to slow down the progression of rigidity in Parkinson's disease. The European Parkinson's Disease Association (EPDA) has identified specific prevention and treatment along with few exercises, activities as shown in figure 12 which could serve as a betterment factor for rigidity and slow the progression of the disease by maintaining flexibility, positive attitude and mobility [42]. A few of them are listed below.

- Consultation with physiotherapist, speech therapy and occupational therapy.
- Inclusion of simple exercises and activities that tire muscles in daily routine along with prescribed medication.
- Maintain a calm and peaceful environment.
- Rearrangement of furnitures and fasten loose rugs securely to avoid fall and access to free movement.

For more information about the list of videos related to coping strategies where users share their own experience on how specific exercises and activities helped them to cope with their daily living, please refer to [42].

Figure 12: Examples of activities to reduce rigidity

4.3 Analysis of solution 3

Postural instability is the incurable symptom among PD resulting in morbidity. But, it can be controlled by practising therapies and exercises, namely balance exercises improves postural instability and gait difficulty. Physical and occupational therapies could helps the patient to reduce the risk of injuries and falls. For some patients with severe postural instability, wheelchair use is recommended for transportation [43].

4.4 Analysis of solution 4

The solution of wearable glasses presented in section 3.4 has the potential to empower people with PD by providing everyday assistance in self-management of their symptoms. The study presented the development for the very first time of a real time detector of FOG episodes implemented on smart glasses. As mention by the authors it is a very promising finding in the approach to the management of the gait symptoms. In fact, previous studies developed a similar system based on accelerometers located in 5 positions of the lower part of the body, meaning an easier detection but a less user friendly solution. By positioning the sensors on the glasses, researchers found that the algorithm still has a 92.86% accuracy, even though less amount of sensors are used and movement is analysed only through the step length.

The potential of the device is remarkable, particularly more functions may be implemented and added to the current one on the glasses such as reminder alerts, calendars, to-do list, which might lead to a considerable improvement of quality life in PD patient in the near future. On the other hand, some issues need to considered. In fact, people suffering from PD, due to their age, tends to reject the technology and wary of the effectiveness of the solution. Another issue that must be mentioned is the fear of fleeting attention related to the use of glasses that can lead to a drop out of the solution. Further, in the last years some concerns have arisen towards the safety, the privacy and the violation of intellectual properties in the use of smart glasses. This might have threatened further development along this track [2]. Nevertheless, it still remains a very interesting finding in the field that ought to be important mentioning.

4.5 Analysis of solution 5

The innovative approach based on using a mobile platform, as presented in section 3.5, has a remarkable potential. The novelty consists of a patient-centered and a multidisciplinary approach with the goal to join the current treatments towards Parkinson's disease. Thus, the following solution proposes a possible monitoring and assessment of PD condition in everyday life. This particular solution underlines for the first time the importance of an holistic overview and approach toward the disease, giving also a considerable importance to non-motor symptoms. Even though there are less evident, these kind of symptoms are what have the greatest impact on the quality of life. On the other hand, no similar mHealth platforms were found during the research process. Likewise, there were not many studies for testing the app. To actually get more evidence of the effectiveness of the platform, additional future studies are needed.

[2] see e.g. reference [44]

4.6 Analysis of solution 6

Although Telemedicine differs qualitatively with in-clinic appointments, it gave a great insight of PD patient's living environment both physically and emotionally to the physicians. One patient who walked with ease at the clinic had terrible bouts of freezing while walking through the crowded living room. Another patient who was asked to stand up from her chair to assess her walk revealed a bundle of tissue in her chair which exposed her emotional feelings that she has been crying from morning much to her daughter's dismay.

The initial experiences with any new technology can be annoying for clinicians as well as for patients, but they manage to rapidly adopted to this model in a short span. In the long term, virtual calls and digital measures can reach a wider geographic spectrum, capture real-time data, and foster participant-centered research studies. However, lack of access to technology to enable Telemedicine is limited in some rural areas, but this digital divide can be bridged by expanding efforts to make it universal.

The apps presented in table 3 offer a chance to the patient to practise digital rehabilitation in alternative to the services given by the community. This can be extremely helpful during odd time like the COVID-19 pandemic. Especially since it has been proved that lack of physical or mental activity lead to a worsening of the symptoms [3]. Another advantage of the solutions presented is that they can overcome the physical and geographical barriers through digital communication. Thus, here lies the potential of eHealth, overcoming physical obstacles and enhancing the outcomes and the quality of life. Moreover, the app presented can help to increase and improve the compliance to the rehabilitation always being within everyone's means of communication and easy to access. On the other hand, the apps seem to address only one issue or symptom at the time, resulting in being confusing for the patient to have to download and learn to use many different Apps, especially since every app is designed differently. Ideally, it would be nice to group all the solution in one big platforms, and adapting the platform to the patient needs.

4.7 Comparison of the presented solutions

Below follows a comparison among the various solutions, in order to stress the main feature and the further improvement that can be taken in the future.

As far it concerns solution 1, 2, 3 and 4, wearable and accessory devices are needed. Solution 1 can be implemented in a smart watch, very spread nowadays and also an affordable device, although it is reduced to limited functionalities. Unfortunately, the same issue is applied to solution 2 along with the user-friendliness resulting in hesitation of people towards the advance technology. On the contrary, even though solution 3 is an accessory as the previous one, users have found it very lightweight and comfortable leading to a more confident way of walking and feel of safety, important aspects since it leads to an improvement of patient's quality of life. Moreover, the product durability must also be mentioned, even though the device needs to be charged wirelessly for 6 hours, it can last for a week.

However, the user-friendliness and patient-centered solutions are features that researches

[3] for further detail see [38].

should pay more attention to in the future. This is to develop promising solutions for PD treatment and management as well as the aim to concentrate the monitoring of the symptoms in less sensors and devices and possible in order to make it easy-to-use and easy-to-wear. Despite this factor, the presented solutions remain very promising and innovative. In particular, the solutions can be the start-idea for further project and developments.

On the other hand, other issues concern the solution 5, 6 and 7. In fact, these solutions seem to be designed to be user-friendly and patient-centered. This is a very good indicator of the possible future spread of use of the platform as well as the methods among patients. As a result, there is the possibility to build a universal library and data collection among the patients that leads to an improvement if compared to the ordinary and current methods. In fact, personal diaries or the opportunity for the clinicians to have a good understanding of the disease itself along with the progression of the disease and the patient conditions are deemed to be a huge potential benefit. Even though they seem to be good solutions, the main concern remains the personal data treatment and the use. Specifically, more studies and works need to be conducted in order to assure a maintained fair use of personal data and having a clear consent from the patient.

4.8 Further developments

Even though the progress and development of the technology is extraordinary fast and over the years there are more and more chances to integrate the current eHealth innovations, unfortunately most of them are not adopted at the moment. There are several reason behind these obstacles. Firstly, the users, especially elderly people, are not confident with the use of tech-devices along with the deployment of one or more devices or platforms that make the solution user-friendly. Moreover, one of the main barriers largely reported among the studies read is the consistence and the adherence of the patient to the treatment leading to a failure or to a inadequate evidence to sufficiently validate the study. In addition, the more sophisticated and innovative the device, the more expensive it is. This aspect, even though is not considered during the study and development phase, is fundamental since it might foresee the usage and the spread among the patients. Furthermore, patients are not willing to spend money even though the benefit is high due to the cost of the devices [44].

As far as the adherence to the treatment is concerned, a recent statistical survey helped to find some of the factors that showed non-adherence to therapy session for PD [45]. The main results of this study are given in figure 13. This clearly shows that '*Lack of importance*' has a higher ratio compared to other factors and that the awareness to detect PD at an early onset is as important to attend the advised therapy sessions to slow down the progression of the disease. This obstacle might be overcome by educating and motivating the patient to the importance of adhering to the treatments as well as creating awareness of the benefits. Moreover, the physiological effects must not be neglected since the impact on the patient quality of life is extremely large. Needing to wear huge, noticeable or uncomfortable devices might lead to the rejection of the same even if there are significant benefits.

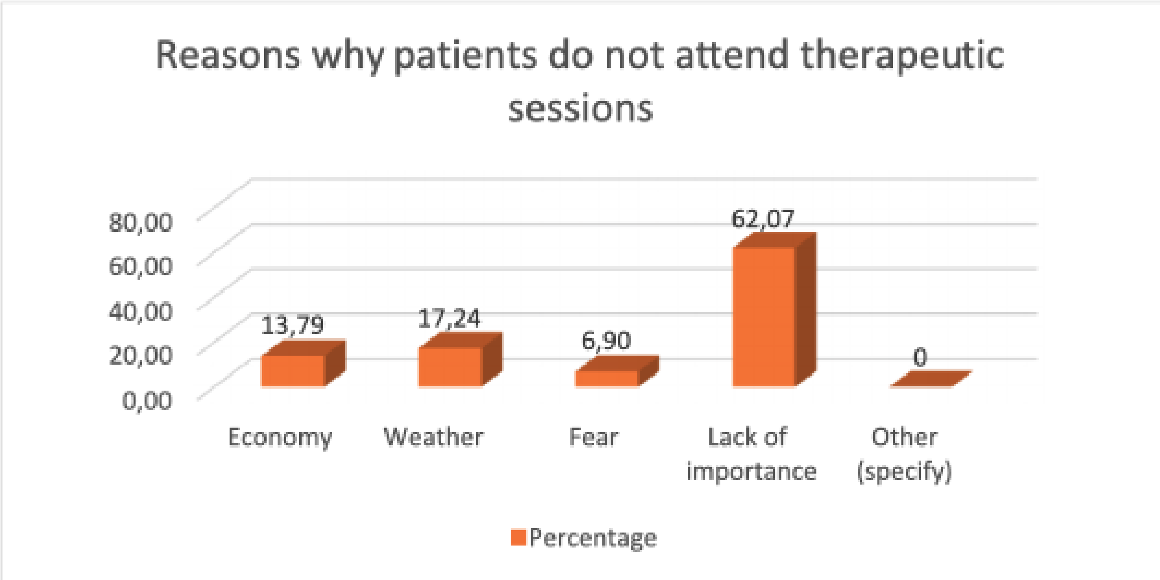


Figure 13: Statistical survey of non-adherence to therapy in PD [45].

5 Conclusion

One of the main aims of this work was to give the reader an understanding of Parkinson's disease in terms of what digital solutions are available today. The chosen solutions had a main aim to treat or monitor symptoms, not to prevent the disease itself. The work was mainly done using a comparative study of various eHealth solutions focused on different symptoms. It was found that the most digital solutions available today focus on some of the motor symptoms in the acronym TRAP. In addition, it was observed that in many solutions, at least one wearable device was needed for tracking one symptom. It was therefore concluded that such solutions are not very likely to be used in combination, since it would result in a person having to wear too many devices on a daily basis. In addition to these solutions, a mHealth solution aimed to track both motor and non-motor related symptoms (such as sleep and anxiety) was presented. It was concluded that such a broad solution was rare, which further was supported by the fact that the previous solutions only were aimed to cover one or two symptoms each. Further, a brief overview of the role of telemedicine was presented. It was concluded that the method had great potential, in particular during the current pandemic. Furthermore, in general it was concluded that there is a lot of scientific research available on various devices aimed to aid people diagnosed with Parkinson's disease. However, there is a lack of devices that de facto have been introduced to the market and few of these can handle several symptoms simultaneously. It was therefore concluded that there is a lot missing regarding these digital solutions, in particular in terms of user-friendliness. The main conclusion of this study is therefore that there is a lot of future potential in regards to eHealth for Parkinson's disease.

A Division of work

During the process, the whole team has had weekly meetings discussing the work in general. Thus, all team members have been involved in the decisions of which digital solutions to present and what to include in the report. Further, Chiara has made a lot of research about the disease itself and provided most of the information found in the introduction, Kanniga has researched a lot of digital solutions and Johanna has had a main responsibility of maintaining a consistency of the report. Collaboration between the team members was overwhelming by always maintaining a positive feedback loop. However, the writing was divided between the group members as presented in the list below.

Abstract: Johanna

1. Introduction
- **1.1.** Background: Chiara, Johanna, Kanniga
- **1.2.** Aims: Johanna
- **1.3.** Limitations: Johanna

2. Methods: Chiara

3. Results
- **3.1.** Solution 1: Johanna
- **3.2.** Solution 2: Kanniga
- **3.3.** Solution 3: Kanniga, Shivani, Chiara
- **3.4.** Solution 4: Chiara
- **3.5.** Solution 5: Chiara
- **3.6.** Solution 6: Kanniga, (Apps - Chiara)

4. Discussion
- **4.1.** Solution 1: Johanna
- **4.2.** Solution 2: Kanniga
- **4.3.** Solution 3: Shivani
- **4.4.** Solution 4: Chiara
- **4.5.** Solution 5: Chiara
- **4.6.** Solution 6: Kanniga, (Apps - Chiara)
- **4.7.** Overall comparison: Chiara
- **4.8.** Further Developments: Chiara, (survey - Kanniga)

5. Conclusion: Johanna

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