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Mobile Applications for People with Parkinson's Disease: A Systematic Search in App Stores and Content Review

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Abstract: Parkinson's disease (PD) is the most common age-related neurodegenerative motor disease. People with Parkinson's have different motor symptoms related to movement, the most common of which are tremor, muscle rigidity and slowness of movement. In addition, there are other problems that are unrelated to motor symptoms, such as sleep behavior disorders, personality changes, pain and depression. Numerous apps designed for people with this disease have been developed in recent years. Due to the diversity of symptoms, there are very many different apps.

Our goal is to carry out a systematic review of available apps related to PD for the operating systems iOS and Android and to assess their features. In addition, we are interested in the usability of the apps. A search for the representative terms "Parkinson" and "Parkinson's Disease", together with the descriptors of the symptoms, was conducted in the Google Play and Apple App stores. Next, we screened the PD-related apps. Finally, we assessed the apps with respect to symptoms, users, purpose and features. In addition, a usability evaluation was carried out.

Key Words: Parkinson's disease; mobile apps; review, systematic; health care technology

Category: H.0, H.3.0, H.3.4, H.4.0, H.4.3, J.0, J.3

1 Introduction

1.1 Background

Parkinson's disease (PD) is the most common movement disorder and the second most frequent neurodegenerative disorder of aging [Mhyre et al., 2012]. Current theories consider that this disorder is the result of a genetic predisposition that possibly interacts with environmental factors such as pesticides, herbicides, and heavy metals. Other factors of daily exposures, such as to the components of the diet, have gained attention as modifiers of the disease [Agim and Cannon, 2015]. Nowadays, Parkinson's disease has no cure, and although many aspects of the neurodegenerative process underlying this disease are known, the treatment of Parkinson's disease is mainly aimed at improving the symptoms derived from neuronal loss [Asociación Parkinson Madrid, 2018].

PD symptoms are many and varied and can differ from person to person, making PD extremely complex to understand and treat. However, it is common for patients with Parkinson's disease to have several of the following motor symptoms: rigidity, tremor, freeze attacks, uncontrollable movements (dyskinesia), slowness of movement (bradykinesia), walking/gait problems, postural instability, lack of balance and falls, writing difficulty, swallowing difficulty (dysphagia), muscle pain, masked face, speech problems and general loss of motor skills [Parkinson's Foundation, 2018]. In addition to motor symptoms, there are non-motor symptoms such as loss of smell, depression and constipation.

Traditionally, motor assessments are carried out by a neurologist who observes the patient performing certain tests or tasks, and uses rate scales to measure the change over time. The problem is the time between appointments with these specialists. New technologies may improve patient-doctor interaction by enabling daily monitoring of PD symptoms. And in this sense, collaboration between professionals and patients can be increased and spatial-temporal limitations reduced. New technologies can also help to assess the evolution of patients.

Different health apps have been developed in recent years, as shown below in the related work section. In particular, there are PD-related apps for the major operating systems, namely Android and iOS. Some of these apps are focused on physical symptoms such as tremor or swallowing problems. Other apps have been developed for clinical trials which collect data about the daily life of people with and without PD. Other apps help to evaluate the rating scales. There are apps designed for assisting patients with PD, caregivers and professionals; and apps which provide detailed information about PD. And some apps combine several of the above aspects. However, there is no single application that covers all aspects of PD. And due to the large number of apps, it is difficult to choose the ones that are most appropriate. Therefore, knowledge of the different approaches is essential when deciding which app is best suited to the needs of each person.

1.2 Related Work

In the literature, most published works about PD apps and new technologies focus on two main fields: the use of applications to treat different PD symptoms, and the evaluation of apps aimed at gait rehabilitation.

Tremor is one of the main symptoms and is measured by smartphones through the accelerometer and gyroscope. Specifically, [Fraiwan et al., 2016] show how a smartphone accelerometer can accurately detect and record rest tremor in patients with Parkinson's disease. [Kostikis et al., 2014] study the correlation that exists between the clinical scores obtained by the standard clinical test *Unified Parkinson's Disease Rating Scale* (UPDRS) [Martínez-Martín et al., 1994] and smartphone measurements of hand tremor in Parkinson's disease patients. They claim that the signals from the accelerometer and gyroscope are objective metrics for quantifying hand tremor.

With respect to apps related to Parkinson's disease gait, [Ellis et al., 2015] test the efficacy of smartphones for gait analysis as an alternative to conventional gait analysis methods based on more expensive and complex devices (e.g., footswitch systems or the sensor-embedded walkways). The app proposed in [Ferrari et al., 2016] performs a precise spatio-temporal analysis of gait patterns using real-time data collected from shoe-worn inertial sensors. [Ginis et al., 2016] describe the effectiveness and feasibility of a particular application for gait training in a domestic environment. [Takač et al., 2013] present a method for the assessment of how the environment, body orientation, and position affect freezing gait. In this case, the measurements are obtained from the internal inertial sensors, the three-axial accelerometers, the gyroscopes, and the magnetometers of the smartphones. [Pan et al., 2015] use mobile technology to collect and monitor PD-related motion data using a smartphone accelerometer, and to send the data to a cloud service for storage and analysis. [Printy et al., 2014] use a smartphone's touch-screen and microphone to correctly classify overall motor impairment, and bradykinesia in particular. [Palmerini et al., 2011] show how Timed Up and Go (TUG) for the assessment of balance, mobility, and fall risk can be performed by using a smartphone's accelerometer as the measurement system. [van der Kolk et al., 2015] present a motivational app as a complement to PD treatments. This app uses gaming elements to encourage patients to exercise. [Wagner and Ganz, 2012] present a smartphone application connected with footswitches and a micro-controller via Bluetooth. This app evaluates the PD patient's gait, and this analysis allows patients to monitor their own gait over time.

Other works related to new wearable technology for improving the PD patient's life include that of [Cohen et al., 2016], in which the authors present an Internet of Things mobile platform using wearable sensors and data management, whose main goal is offering possibilities for more reliable, low-cost and robust PD patient care methodologies and strategies. This platform is the result of collaboration between the Michael J. Fox Foundation for Parkinson's Disease Research [The Michael J. Fox Foundation, 2018] and Intel Corporation [Intel, 2018]. [Pachoulakis et al., 2015] present several gaming platforms using virtual reality games, which try to promote the physical training of patients with PD.

As far as we know, there are very few works that carry out a thorough study of apps for PD that are currently on the market. The most closely related one can be found in [Rey et al., 2017], where the authors present a systematic review of PD apps, but most of the paper is written in Spanish, and only the abstract is in English. They present a table of apps, but they do not present an assessment of the apps. Furthermore, we also detail the different PD symptoms that each app is designed to tackle. There are similar papers to ours but for different health areas such as breast cancer [Giunti et al., 2018], multiple sclerosis [Giunti et al., 2017], or diabetes [Gao et al., 2017].

1.3 Objective

Our goal is to review the apps available for Parkinson's disease in the Google Play and iOS stores and study whether one operating system is better than the other. We are also interested in knowing what symptoms of Parkinson's are treated and what types of users are targeted. Finally, we are interested in learning whether the usability of these apps is acceptable.

2 Methods

2.1 Search Strategy

Our systematic review has been carried out on the two most common operating systems for mobile devices: Android (Google Play) and iOS (App Store). At first, we searched for the English terms "Parkinson" and "Parkinson's disease" to identify publicly accessible apps. However, we detected several apps that, although not appearing in the result for these search terms, were nevertheless strongly related to the most common symptoms in patients with the disease. For this reason, we identified additional terms that describe the symptoms of this disease in order to ensure that the search result contains the largest number of related PD applications. These additional terms are the following: "akinesia", "bradykinesia", "freezing of gait", "freezing gait", "imbalance", "dyskinesia", "dysphagia", "dystonia", "hypomimia", "instability", "postural instability", "Parkinsonian gait", "festination", "rigidity", "tremor", "tremor at rest", and "tremor rest" [Jankovic, 2008, Pahwa and Kelly, 2013].

The set of applications reviewed in this article are part of the result of the search carried out in December 2017 in Android Play Store and in March 2018 in iOS App Store.

2.1.1 iOS Search Strategy

The analysis of iOS apps was conducted using the information obtained from the iTunes Search API [Itunes, 2018]. This API allows the use of filters and provides useful information about each app in a JSON document. This document was loaded and processed by means of a Python program in order to build a dataset with only the relevant information for every app in the search result. Subsequently, we selected only apps in the subcategories "Medical", "Health & Fitness" and "Education" for our analysis.

2.1.2 Android Search Strategy

We retrieved the information about Android apps using the google-play-scraper library [Google Play Scraper, 2018]. This is a non-official javascript library that is publicly accessible. This library allows us to query the Google Play market. The results of the queries are an easily analyzable object that can be exported to CSV format. The queries in Google Play can be by "category" or by "term", but not both at the same time. The queries in categories did not provide a satisfactory result, so we chose to perform a query with the terms listed above.

2.2 Screening

2.2.1 Inclusion and Exclusion Criteria

We have included in our study all the apps returned by the search mentioned in the previous section. These apps were screened to exclude non-PD related apps. This screening was performed by the authors of this work, holding discussions and reaching a consensus in case of doubt.

Non-PD related apps were excluded for different reasons: the surname of one of the authors is Parkinson or the app followed the so-called Parkinson's law or because the app deals with the Wolff-Parkinson-White syndrome. We also excluded apps that are too generic, i.e. apps that are applicable to a large number of diseases or illnesses. Neither did we include apps aimed at congresses, or the management of hospitals, clinics, or residences for the elderly. Apps not available in English were also excluded.

2.2.2 Adjustments

In the screening process we detected that four apps had scarcely significant variations in name. In order to make the comparisons correctly, one of the two names was chosen. These apps are: Beats Medical - Beats Medical Parkinson's Treatment, LSVT Global Loud - LSVT Loud, Parkinson Home Exercises - Parkinson Exercises Mobile, and DAF Pro - DAF Professional.

2.3 Assessment

Upon initial screening, we noticed that apps dedicated to PD were very different from each other. Just as there are different symptoms of the illness, there are different kinds of applications. Therefore, we have decided to review each app considering the Parkinson's symptoms described in U.S. National Library of Medicine [U.S. National Library of Medicine, 2017]. We have avoided technical names, such as Bradykinesia or Dystonia and some symptoms are not addressed because they are not captured by any app, e.g. "Excessive sweating". Categories and Subcategories of our classification are shown in Table 1.

In addition to the symptoms treated, we also checked for what type of user the app is intended, e.g. for patients or health professionals, and whether it is for clinical trials. Clearly clinical trials are performed by professionals, but we have separated this field from the field of professionals because these apps are intended to be used by clinical researchers to collect specific research data.

A large number of apps are focused on monitoring and recording information related to the progress of the disease. This purpose has also been added.

The global assessment of all considered apps is available in a Excel spreadsheets included in the website `http://antares.sip.ucm.es/~sonia/RISEWISE/en_park`. All the information about each considered app is in a row in this table. In the columns of the table there is the information of each app: the symptoms it is related to, the target user of the app (patient or professional), and its purpose (monitor or informative). For the tests we used a Samsung Galaxy j5, 2016 (Android 7.1.1), an iPhone 8 Plus, 2018 (iOS 11.2.6), and an iPad A1432 with iOS 9.3.5.

Some apps have only been partially tested or not tested at all. The reasons are either that they need a device that we do not have (e.g. the app Be Bionic uses a mannequin) or because they are clinical trials and require identifiers given in clinics and passwords (e.g. the app cloudUPDRS). However, they have been included because there are few of them and we find it interesting to have some knowledge of these apps. In these cases, we have classified the app based on the app store description. These kind of apps are labeled in the global assessment as *Features-Requires external accessory*, and *Clinical trials or experimental evaluations*.

2.3.1 Usability

The usability of an application is an essential feature and indicates how simple or complicated the user interfaces are. In this work, the usability evaluation has been performed following the general principles of Jacob Nielsen [34], in a similar way to that in [Axelrod et al., 2014]. Nielsen proposes a usability inspection method summarized in ten principles (Table 2) that help to identify usability

Category	Subcategory
General symptoms	Problems with balance and walking
	Rigid or stiff muscles; muscle aches and pains
	Stooped posture
	Difficulty swallowing and eating
	Drooling
	Slowed, quieter speech and monotone voice
	No expression on face; slow blinking
Movement problems	Difficulty starting movement, such as starting to walk or getting out of a chair
	Difficulty continuing to move
	Slowed movements
	Loss of small hand movements (writing may become small and difficult to read)
Symptoms of shaking (tremors)	-
Users	Patients
	Health professionals and caregivers
Clinical trials or experimental evaluations	
Purpose	Periodic monitoring of symptoms (health diary)
	Information or education
Features	Pro/trial
	Requires external accessory

Table 1: *Classification of Symptoms to Assess*

problems in the user interface design. In our case, we evaluate a subset of apps, specifically a 25% sample. The criteria for selecting the sample was to choose the apps with the highest number of user ratings. Ideally, the selection should be performed randomly, but we have followed a different approach because we wished to obtain homogeneous results for the two markets: Android and iOS.

The evaluation of Nielsen's principle 5 (Error prevention) has allowed encountering some errors on the evaluated apps. We have considered errors on apps those with grade strictly inferior to 3. Specifically, 3 apps evaluated with a grade of 1: Shaky Hands, Parkinson's Central (Android), Parkinson's Disease Monitor & Commentary (IOS), and 1 app got a grade of 2: Parkinson's Toolkit (Android). Shaky Hands app crashes, then its poor grade is due to it. However, Parkinson's Central app works properly, but it shows a warning during its whole functioning, which is not managed. Regarding Parkinson's Disease Monitor & Commentary app, its low grade is due to it does not work for mobile with iOS 11 system. And finally, Parkinson's Toolkit app contains not working links.

Heuristic	Description of the heuristics
1. Visibility of system status	The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
2. Match between system and the real world	The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.
3. User control and freedom	Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.
4. Consistency and standards	Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.
5. Error prevention	Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.
6. Recognition rather than recall	Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.
7. Flexibility and efficiency of use	Accelerators -- unseen by the novice user -- may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.
8. Aesthetic and minimalist design	Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.
9. Help users recognize, diagnose, and recover from errors	Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
10. Help and documentation	Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

Table 2: *Jakob Nielsen's 10 general principles for interaction design*

3 Results

3.1 Screening

The results of the initial search for applications consisted of 485 Android apps and 133 iOS apps. After the screening, we obtained a total of 54 apps, 16 of which are available for both operating systems. The results can be found in

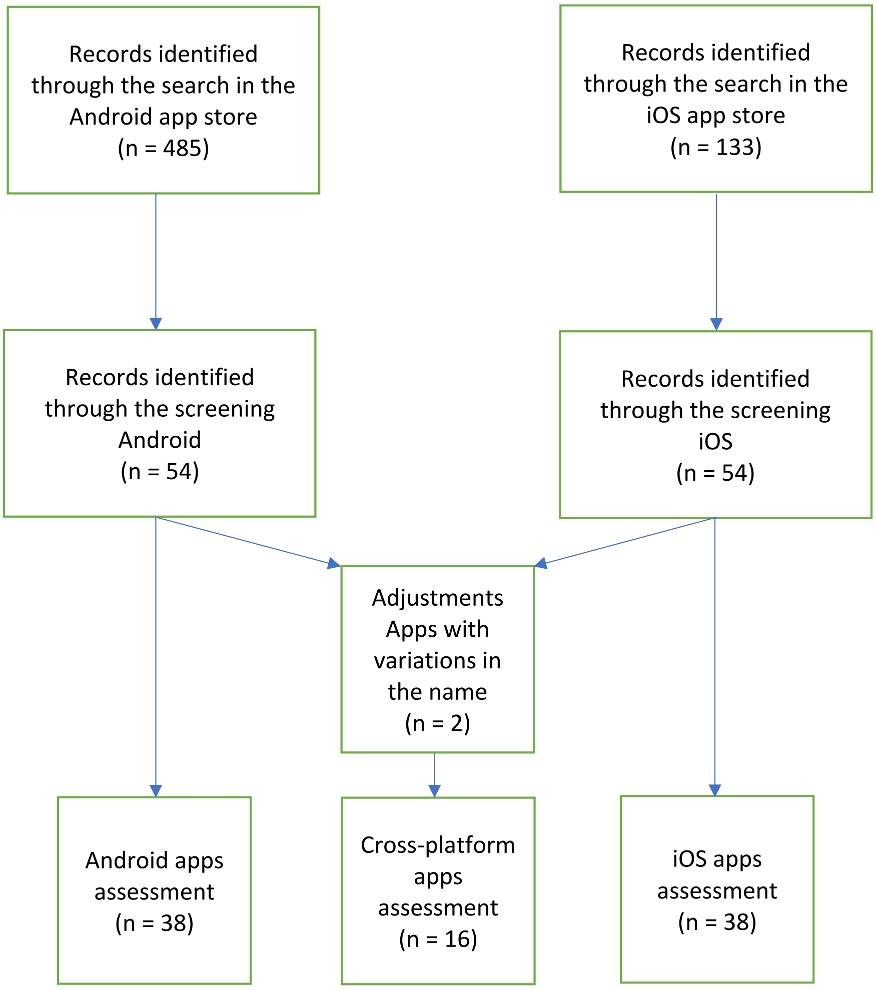

Figure 1: *Flow diagram illustrating the exclusion of apps in the screening*

the Excel spreadsheets available in the website `http://antares.sip.ucm.es/~sonia/RISEWISE/en_park`, as mentioned before. Details about the exclusion and adjustment of apps are provided in Figure 1.

3.2 Assessment

3.2.1 Symptoms

Having labeled all the apps with respect to the General Symptoms, Movement Problems and Purpose in Table 1, the corresponding percentages are shown in

Category	Symptoms	iOS n=38	Android n=38	iOS & Android n=16	iOS Total n=92
General Symptoms					
	Tremors	9(24%)	14(37%)	2(12%)	25(27%)
	Rigid or stiff muscles	7(18%)	8(21%)	5(31%)	20(22%)
	Problems with balance and walking	7(18%)	8(21%)	3(19%)	18(20%)
	Slowed, quieter speech and monotone voice	7(18%)	4(11%)	7(44%)	18(20%)
	Difficulty swallowing and eating	6(16%)	5(13%)	2(12%)	13(14%)
	Stooped posture	6(16%)	2(5%)	2(12%)	10(11%)
	Drooling	0(0%)	1(3%)	3(19%)	4(4%)
	No expression on face	0(0%)	1(3%)	1(6%)	2(2%)
Movement Problems					
	Slowed movements	14(37%)	10(26%)	5(31%)	29(32%)
	Difficulty continuing to move	6(16%)	9(24%)	4(25%)	19(21%)
	Difficulty starting movement	6(16%)	9(24%)	3(19%)	18(20%)
	Loss of small hand movements	4(11%)	2(5%)	3(19%)	9(10%)
Purpose					
	Periodic monitoring	13(34%)	10(26%)	8(50%)	31(34%)
	Information or education	10(26%)	13(34%)	5(31%)	28(30%)

Table 3: *App distribution by Symptoms, Movement Problems and Purpose, n(%)*

Table 3.

The results in Table 3 are represented in Figure 2 and show that there are more apps dedicated to monitoring symptoms (34%, 31/92), than to specifically treating any particular symptom. Nevertheless, the four cardinal PD symptoms (TRAP: tremor, rigidity, akinesia/bradykinesia and postural instability) are addressed by a significant number of apps: tremor (27%, 25/92); rigidity or muscle

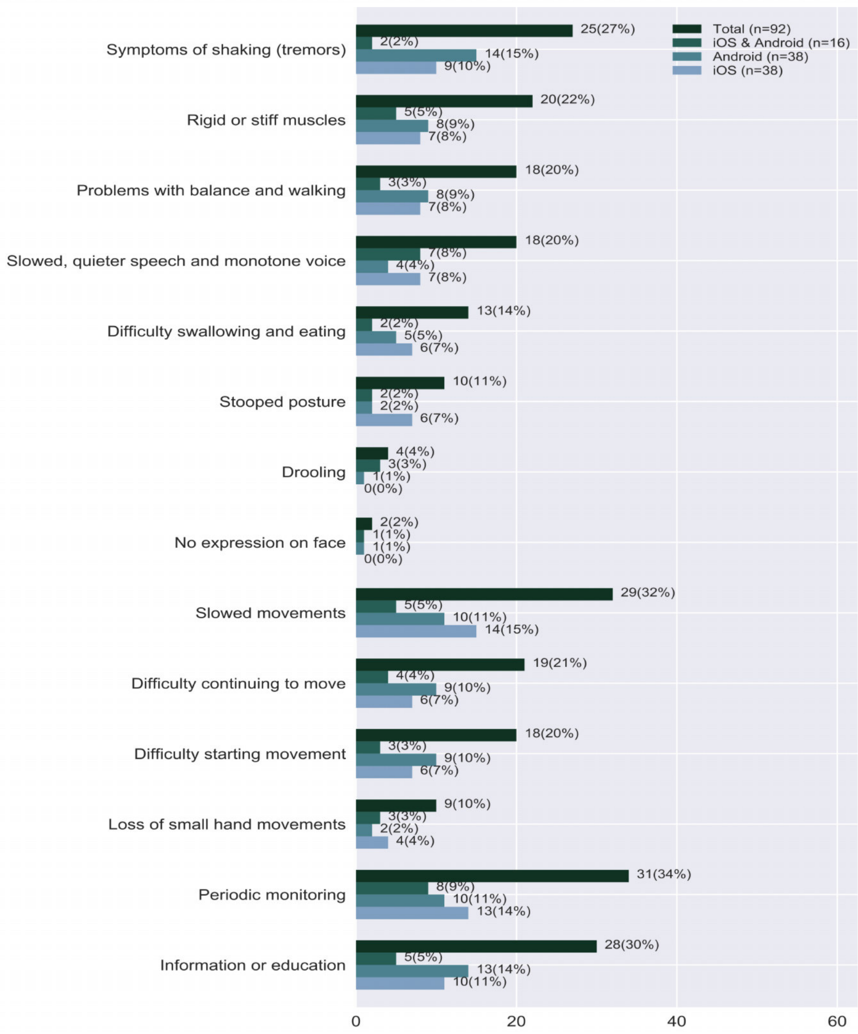

Figure 2: *App distribution by operating system and category*

stiffness (22%, 20/92); bradykinesia and akinesia, which are characterized by slow movement (32%, 29/92) and loss of ability to move muscles voluntarily (20%, 18/92); and postural instability or problems with balance (20%, 18/92). These primary symptoms of Parkinson's are directly related to the rest of the symptoms. In particular, akinesia and bradykinesia are associated with movement problems, such as difficulty in continuing a movement (21%, 19/92) and

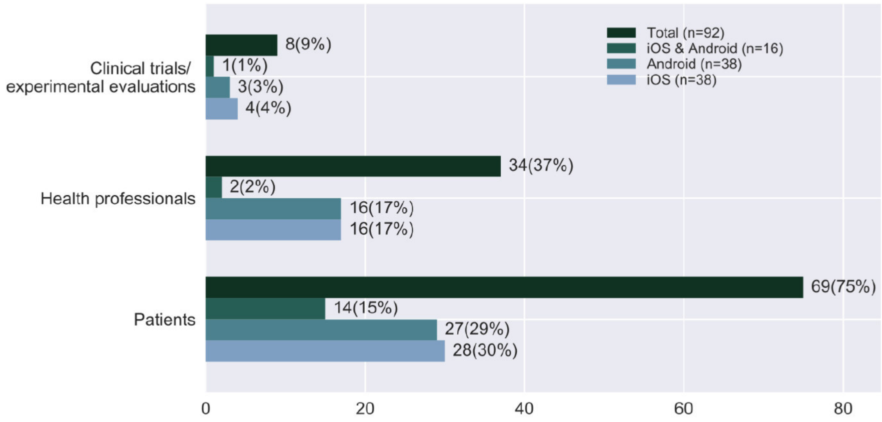

Figure 3: *App distribution by operating system and target users*

fine motor control such as writing, sewing, or getting dressed (10%, 9/92). Other motor symptoms include a stooped posture (11%, 10/92) and mask-like facial expression (2%, 2/92).

With regards to speech and swallowing disturbance there are also a reasonable number of apps, (20%, 18/92) and (14%, 13/92), respectively. Even drooling is represented (4%, 4/92). Lastly, there is also a significant number dedicated to information and education (30%, 28/92).

3.2.2 Apps' Target Users

Our study shows great differences in the number of applications depending on the type of users they are aimed at. Figure 3 shows that the target of 75% (69/92) of the apps is patients, while 37% (34/92) is aimed at health professionals, and only 9% (8/92) of apps are designed for clinical trials/experimental evaluations.

3.2.3 Acquisition Costs

An important aspect is the purchase cost, and this is summarized in Table 4. The vast majority of the studied apps were free, 63% (58/92), while only 37% (34/92) correspond to paid apps (Table 4). We can also observe that the ratio of free to paid applications between the two systems is similar.

When considering only paid apps, the price differs slightly between the two operating systems, as shown in Figure 4. Of the total paid apps, 73% (25/34) were in the price range of \$0.99 to \$9.99. The analysis shows that the price of 50%

	iOS (n=38)	Android (n=38)	iOS & Android (n=16)	Total (n=92)
Free	25(65%)	24(63%)	9(56%)	58(63%)
Paid	13(34%)	14(36%)	7(43%)	34(37%)

Table 4: *Acquisition Costs by operating system*

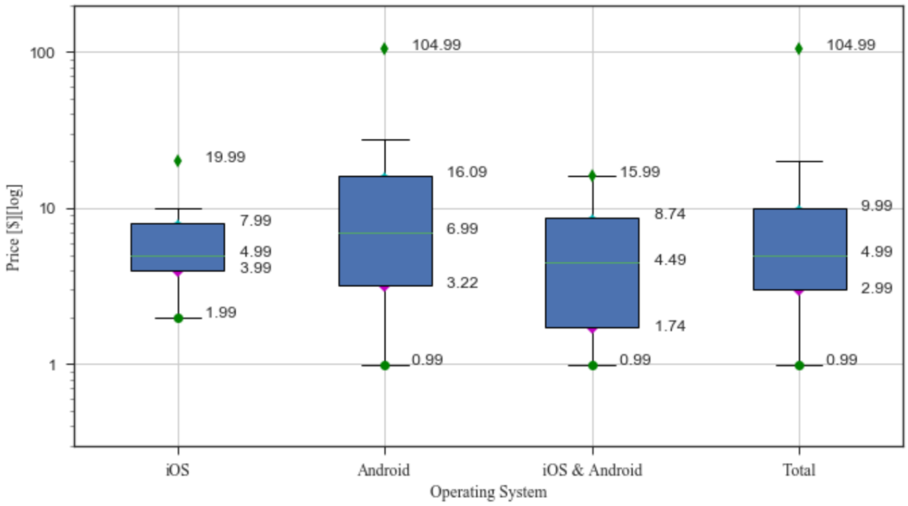

Figure 4: *Cost distribution by operating system*

of iOS apps is concentrated in the range of \$3.99 to \$7.99, compared with the Android operating system where the price of 50% of the apps is scattered over the range of \$3.22 to \$16.09. The minimum price was \$0.99 and the maximum was \$104.99.

3.2.4 Popularity and User Rating

Table 5 summarizes the data collected with respect to this aspect and reveals that the number of applications rated differed considerably between the two operating systems. While only 31% (12/38) of the iOS apps were rated by users, the vast majority of Android apps were rated (68% (26/38)). This also occurs among the apps running on both systems, where only 43% (7/16) of iOS apps were rated compared with 87% (14/16) in the case of Android apps.

The analysis shows that the median of the number of rates varied between 2 (iOS apps) and 8.5 (Android apps running on both operating systems). Taking

	iOS (n=38)	Android (n=38)	iOS & Android (n=16)	
			iOS	Android
Apps with ratings, n (%)	12(31%)	26(68%)	7(43%)	14(87%)
Median number of ratings	2.0	3.5	8.0	8.5
Median number of stars	3.2	4.2	4.5	4.1

Table 5: *User Rating of Apps*

into account that an app's evaluation can achieve a maximum of 5 stars, 50% of the PD apps earned ratings of more than 3.2 (apps developed exclusively for iOS) up to 4.5 (iOS apps running on both systems) stars. In the case of apps running on both systems, there was no major difference between the median number of stars for iOS apps and Android apps. However, there was a big difference in the case of applications designed exclusively for iOS or Android.

3.2.5 Usability Evaluation

For each app, the 10 entries are evaluated with a score ranging from 1 (poor) to 5 (excellent). The average of these ten scores is shown in the "usability" field of Table 6. The details of the scores can be found in `http://antares.sip.ucm.es/~sonia/RISEWISE/en_park`

4 Discussion

As a short summary of the results, we can observe that the most common symptoms of PD are treated by at least one app. Most of the apps are targeted at monitoring the symptoms of patients, and the apps targeted at professionals are informative. Below, we outline some of the research that the apps are based on. Then, we compare the differences between the two platforms and discuss the usability results. We conclude this section by discussing the limitations and the conclusions of the paper.

As we expected, apps cannot be considered as medical devices, except those apps involved in clinical trials. However, there are several apps that are based on research. There are several neuropsychological tests that can be used to measure motor speed, motor control, and coordination: the Finger Tapping Test (FTT) [Axelrod et al., 2014, Yokoe et al., 2009], the Two Index Finger Test, the Middle Finger Test [Rafal et al., 1987], and the Action Research Arm Test [van der Lee et al., 2001]. Apps based on finger-tapping tests are a simple way to

	iOS (n=12)	Android (n=12)	iOS & Android (n=2)	Total (n=26)
	Mean (SD)			
1. Visibility of system status	4.3(1.2)	3.2(1.9)	5.0(0.0)	3.9(1.6)
2. Match between system and the real world	4.8(0.4)	4.2(1.4)	5.0(0.0)	4.5(1.0)
3. User control and freedom	4.5(1.2)	3.6(1.7)	5.0(0.0)	4.1(1.5)
4. Consistency and standards	4.6(1.0)	4.0(1.7)	5.0(0.0)	4.3(1.3)
5. Error prevention	4.7(1.2)	3.8(1.6)	5.0(0.0)	4.3(1.4)
6. Recognition rather than recall	4.2(1.1)	4.3(1.1)	5.0(0.0)	4.3(1.0)
7. Flexibility and efficiency of use	5.0(0.0)	5.0(0.0)	5.0(0.0)	5.0(0.0)
8. Aesthetic and minimalist design	4.8(0.4)	4.2(1.1)	4.5(0.7)	4.5(0.9)
9. Help users recognize, diagnose, and recover from errors	4.7(1.2)	3.8(1.6)	5.0(0.0)	4.3(1.4)
10. Help and documentation	4.2(1.1)	2.8(2.3)	4.5(0.7)	3.5(1.9)
Average of scores	4,6(0.9)	3,9(1.4)	4,9(0.1)	4.3(1.2)

Table 6: *Usability Evaluation*

test the power state of the central nervous system, motor speed, lateralized coordination, and the effects of cognitive impairment [Rabinowitz and Lavner, 2014]. In our review there are several apps that include some variant of finger-tapping tests and one app helps to perform the Action Research Arm Test (ARAT).

Some research suggests that rhythmical auditory cueing and visual cueing help patients to increase regular cadence [Lim et al., 2005, Lee et al., 2012], movement initiation and stride length. Different methods such as Rhythmic Auditory Stimulation (RAS) [Thaut et al., 1996] and Metronome Therapy [Enzensberger et al., 1997] have been used in physical therapy to improve the so-called Parkinsonian gait and mobility in general. Both methods suggest that external rhythmic stimulation can provide the necessary trigger to switch a step in a movement sequence. Apps use these methods to try to generate a gait pattern of normal velocity, cadence and stride length.

One of the most commonly used scales in the assessment of patients with PD is MDS-UPDRS [Martinez-Martin et al., 2015]. Two apps (UPDRS and CloudUPDRS CUSSP) help doctors to evaluate patients using this scale [Prashanth and Roy, 2018].

There are other tests dealing with the usual postural instability, which is a frequent symptom, such as the standard neurological assessment test Timed Up and Go (TUG) [Zampieri et al., 2009], and there are two apps that perform these balance and movement tests (AppTUG Home/Clinic and OPDM Mobility).

Stuttering or stammering may appear during the course of PD [Anderson et al., 1997, Jahromi and Ahmadian, 2018]. Delayed Auditory Feedback (DAF) is a speech and language therapy that induces patients to speak more slowly and to vocalize. This therapy consists in slightly extending the time between speech and auditory perception [Yates, 1963, Lozano and Dreyer, 1978, Chesters et al., 2015]. Multitalker babble is another therapy, and this simulates a murmur that forces the user to speak up [Leszcz, 2012], and pitch-shifting frequency-altered auditory feedback changes the tone of the user's voice for clearer speech [Sathya and Victor, 2015]. In addition, there are apps that improve the positions of the mouth and tongue with exercises. Usually, these apps also deal with the vocal volume level. In our review three apps (DAF Pro, Simply DAF and Dysphemia SMART DAF) are based on these therapies. Furthermore, one app (Earlystimulus) advises whether patients can receive Deep Brain Stimulation (DBS) therapy [Bronstein et al., 2011].

Tremor can be measured in different ways [Niazmand et al., 2011]. One way is by using the phone's gyroscope and accelerometer. Another way is by studying the traces of writing and drawing an Archimedean spirograph by means of an expert system [Sadikov et al., 2015]. Some apps also study how different factors such as medication, sleep, exercise or stress affect tremor. Therefore, it is necessary to add details such as which hand is used, stress levels, the amount and quality of sleep, medication including the dosage level, and general data such as gender or year of birth. There are 23 apps that measure tremor.

Regarding the distribution of "General Symptoms" and "Movement Problems" apps (Table 1), we can say that the distribution is fairly uniform, as all apps are between 14% and 25%, except: stooped posture (10/92, 10%), drooling (4/92, 4%), no expression on face (2/92, 2%), and loss of small movements (9/92, 9%). The first three may be more complex to implement, but we were surprised that the fourth appears only in 9 apps out of the 92. [Norman and Héroux, 2013] provide a review of measurement tools for fine motor skills. In this work tools appear that have already been used in apps such as the Nine Hole Peg Test and Spiral Drawing, and they describe other tools that are not present in the apps in this review, such as the Purdue Pegboard Test or the Box and Block Test. In this sense, mobile applications can be used in studies such as that of [Hwang et al., 2013].

The diversity of terms and the progress of research foster the development and improvement of apps dedicated to gathering information, reports, and professional documentation. There are 29 apps that provide medical guidelines and essential information on topics related to PD which serve as reference and source of information.

4.1 Cognitive impairment

Although we have not considered cognitive deterioration as a symptom of PD, it can appear throughout the disease and the severity varies widely. It is estimated that approximately 20-50% of people with Parkinson's disease, without dementia, have a mild cognitive impairment, and longitudinal studies reveal that around 80% of PD patients will develop dementia [Goldman et al., 2018].

The usual cognitive symptom in the mild cognitive impairment of people with PD is "executive dysfunction" [Kalbe et al., 2016], which is an alteration of the executive processes such as internal control of attention, set shifting (ability to unconsciously shift attention between one task and another), planning, inhibitory control, and the concurrent performance of two tasks, with deficits in a range of decision-making and social cognition tasks [Dirnberger and Jahanshahi, 2013]. There are works, such as [Paolo et al., 1996, Hsieh et al., 2008, Antao et al., 2013], which indicate that training with tests such as card sorting test, digit span backward, word list recall, the Stroop test and, Flanker are good for people with PD. This kind of tests or games have been found in different applications as separate modules, that is, they are not the main objective of the application but they are found as one more tool to use. In addition, they can be easily added to any app.

4.2 Results by App user types

So, the conclusions are, as we have mentioned above, the target of the majority of apps (75%, 69/92) is patients, the target of 37% (8/92) is health professionals and the target of 9% (8/92) is clinical trials. We observe similar ratios (Table 7) if we consider the distribution among operating systems. These results are similar to those in [Arnhold et al., 2014], where they perform a similar study for diabetes. Their ratios for apps targeted at patients are even higher than ours. Possible factors behind these ratios are:

- The target audience is larger in the case of patients than in the case of health professionals and the number of downloads is important to the developers.
- The apps try to monitor the evolution of the patient's symptoms individually.

	Android (n=38)	iOS (n=38)	Android & iOS (n=16)
Patients	27 (71%)	28 (74%)	14 (88%)
Health Professionals	16 (42%)	16 (42%)	2 (13%)
Clinical Trials	3 (8%)	4 (11%)	1 (6%)

Table 7: App Target User by Operating System

– Health professionals cannot rely on mobile phones since they cannot be considered medical devices.

4.3 Usability

In general, the results of the evaluation using Nielsen's usability principles are good and this may be due to several reasons. First, some of these apps are very simple, which means they do not contain faults and are easy to use, for example, there are apps that only measure tremor. Second, we have chosen the apps with the highest user ratings, so we can expect a minimum level of quality in the selected apps. Another reason for the good usability evaluation is that there are apps developed for clinical studies, by associations or professional programmers, and these apps have been developed responsibly. Consequently, the apps have a good score for most usability principles. However, there are some applications that are relatively old and that do not work properly on modern versions of the operating systems; these applications have obtained low grades.

When comparing the usability of the operating systems we can observe that the usability score is clearly higher in the cross-platform apps. The iOS apps have slightly better scores in usability than the Android apps. After the evaluation of usability, we can conclude that all the apps have a good score for most usability principles.

4.4 Operating system differences

We have compared the two operating systems (Android and iOS) in Figure 2 and Figure 3. Figure 2 shows the distribution of apps with respect to the symptoms and the operating systems. All symptoms are treated by both operating systems. The number of apps is similar in both systems for all symptoms, except in 'stooped posture', where there are 4 apps for Android and 8 for iOS (including those for both operating systems). Figure 3 compares the systems with respect to their users (patients or professionals).

When comparing the usability of the considered operating systems, we observe that the better scores and lower standard deviation correspond to the apps that are common to both systems (iOS & Android), the average score being 4.9 and the standard deviation 0.1. The iOS-only apps have an average score of 4.6 with a standard deviation of 0.9. The Android-only apps have the worst score with the lowest average (3.9) and the highest standard deviation (1.4).

4.5 Limitations

The search criteria were generated with the words commonly related to PD ("Parkinson's" and "Parkinson's disease") and a set of specific terms detailed in the Search Strategy section. However, a user searching for a particular type of app can perform a different search, for example, "exercises to improve balance" or "fundraising apps for PD". If another search is applied, different results are obtained. In these results there will be apps that are not in our review. In fact, apps not related to PD and useful for a person suffering from PD may appear. This is a limitation that must be taken into account.

In order to have comparable usability results for the operating systems, we have selected the top 25% apps with respect to the number of user ratings. However, we have to take into account that there is a large number of apps with few ratings; we can assume that these apps are barely used.

Another limitation is that apps can be expanded with new tools. For example, an app that only uses the metronome can easily be extended to measure tremor or dexterity. In this way, the symptoms treated by an app may vary over time. It is also possible that the apps undergo modifications to their states (e.g. price), or even disappear from the market in the future. Therefore, it must be remembered that this review is based on the search results found in December 2017 for Android apps and in March 2018 for iOS apps.

The measure of the quality of an app is an issue that has not been covered in this paper, although we have evaluated an aspect related to quality, namely usability. Neither have we evaluated the privacy aspects of apps. This is something that is also worth of study, as it goes beyond the existence of privacy policy statements. It involves the apps using the granted resources properly. That is, although a user allows an app to use the camera and access to the Internet, the user surely does not want the app send photos to a private server.

4.6 Conclusions

The target of most apps is the patients. These apps help them to monitor their symptoms and perform exercises (physical and mental), and incorporate useful tools such as medication reminders. There are also informative apps that advise professionals about details of the disease and apps that serve as support to evaluate PD-scales or collect data for clinical trials.

All the characteristic symptoms of the disease are treated by at least one app, but there is no single app that deals with all the symptoms. Thus, people with PD may choose the app according to their needs. For example, there are apps dedicated exclusively to voice dysfunctions and others to tremor; the treatment of a specific symptom one often requires a specific app. The classification table, which is available in `http://antares.sip.ucm.es/~sonia/RISEWISE/en_park`. can help people with PD to choose the apps that best suit them in accordance with their symptoms. As future work, it is interested to develop a tool that offers the inverse search, that is, an app or a web site that, given a set of symptoms, search the apps that handle them.

When comparing the operating systems (Android and iOS), we can see they are similar in terms of the number of apps or the symptoms that are treated. The choice of an operating system depends more on the user's preferences than on its capability to address a specific issue.

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A Abbreviations

PD Parkinson's disease

App Application

RAS Rhythmic Auditory Stimulation

TUG Timed Up and Go

FTT Finger Tapping Test

DAF Delayed Auditory Feedback

DBS Deep Brain Stimulation

TRAP Tremor Rigidity Akinesia/Bradykinesia Postural instability

MDS Movement Disorder Society

UPDRS Unified Parkinson's Disease Rating Scale