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DEPARTAMENTO DE TEORÍA DE LA SEÑAL Y COMUNICACIONES, E INGENIERÍA TELEMÁTICA

TESIS DOCTORAL:

Review and Analysis of mHealth Applications. Development and Evaluation of a Heart Diseases Self-Management App

Presentada por Borja Martínez Pérez para optar al grado de doctor por la Universidad de Valladolid

Dirigida por:

Miguel López-Coronado Sánchez-Fortún e Isabel de la Torre Díez

To my mother,

who will always be with me

A mi madre,

que siempre estará conmigo

Agradecimientos

Para asegurarme que todos los mencionados se enteran escribiré esto en español.

Quiero dedicar y agradecer este trabajo de manera especial a mi madre, la mujer de la sonrisa perenne, a quien he amado, amo y amaré siempre, y a quien estaré eternamente agradecido porque me lo ha dado todo y yo a ella muy poco. Durante la realización del mismo, ella estuvo luchando contra la enfermedad que acabó finalmente por llevársela de mi lado. Hasta entonces siempre me estuvo apoyando de todas las maneras posibles incluso anteponiendo mi tesis al hecho de pasar sus últimos días conmigo. Doy gracias a Dios todos los días por haberla desobedecido una última vez y haberme quedado con ella hasta el final. Por tanto, para paliar el gran debe que tengo con ella, este trabajo es para ella, como lo serán todas las acciones y obras que realice a partir de ahora.

Obviamente, no me olvido de mis familias, la de siempre y la nueva, a quienes también dedico este trabajo. Eternas gracias a mi padre y a mi hermano, que han compartido mis penas y alegrías y me han aguantado siempre, a las buenas y a las malas, que es mucho decir. Ambos se merecen lo mejor. Gracias también a Cristina, mi nueva familia, mi queridísima futura mujer, que siempre ha estado al día con mi tesis, aguantando mis quejas y mis enfados, ayudándome con el inglés de las publicaciones, siempre sin quejarse, apoyándome y aconsejando cuando lo necesitaba. Con toda seguridad, la que más me ha sufrido en esta etapa, siempre con paciencia y comprensión. No hay palabras suficientes para agradecérselo. Sin ella, tengo clarísimo que este trabajo habría costado el doble o el triple.

Gracias a mis directores de tesis, Isabel y Miguel, por haberme dado esta oportunidad y la ayuda prestada en el camino. Gracias también a todos los que de algún modo u otro me han ayudado a sobrellevar este período, con mención especial a mi abuela, mis tíos, mis primos, la cuadrilla extendida, los de Laredo, y todos aquellos que se me están olvidando, ellos saben quienes son.

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Resumen

En los últimos años, Internet ha llegado a casi todas las zonas del mundo y nuevas tecnologías han sido descubiertas y creadas, especialmente en comunicaciones móviles. Estas tecnologías han propiciado el desarrollo y rápida expansión de dispositivos móviles como los smartphones y tablets, y, con estos dispositivos, una nueva industria software: la industria de las apps móviles. Actualmente hay apps para cualquier aspecto de la vida, videojuegos, educativas, de productividad y, por supuesto, apps centradas en el cuidado de la salud. Estas apps relacionadas con la salud son parte de lo que se conoce como salud móvil o mSalud, definido por la Organización Mundial de la Salud (OMS) como "*práctica de salud médica y pública realizada con ayuda por dispositivos móviles, como teléfonos móviles, dispositivos de monitorización del paciente, asistentes digitales personales (PDAs), y otros dispositivos inalámbricos*". Por tanto, el objetivo de las aplicaciones y sistemas de la mSalud es combatir las condiciones y enfermedades que minan la salud de los pacientes intentando diagnosticarlas, tratarlas o aliviarlas.

Este trabajo tiene dos objetivos principales. El primero es realizar una revisión de las apps móviles existentes centradas en enfermedades o condiciones no comunicables, especialmente en el campo de la cardiología. Esta revisión se basó en las condiciones más prevalentes, las enfermedades líderes en mortalidad y las enfermedades cardíacas. Fue además complementada con una revisión de Sistemas de Ayuda a la Decisión Móviles (SADM). El segundo objetivo es el diseño, creación y desarrollo de una app móvil innovadora en el campo de la cardiología, con el objetivo de copar un hueco comercial encontrado en la revisión anterior. Para llevar a cabo dicho objetivo, varios estudios fueron realizados para solucionar los problemas encontrados. La experiencia aprendida es compartida con investigadores y desarrolladores con el objetivo de ayudarles en el proceso de creación de apps de mSalud.

La revisión fue realizada en etapas diferentes y llevada a cabo tanto en sistemas y bases de datos académicas (*IEEE Xplore, Scopus, Web of Knowledge, PubMed*) como comerciales (*Google play, App Store*), siguiendo una serie de requisitos. Se obtuvieron varios resultados, como la distribución de trabajo realizado en las distintas enfermedades, la evolución del mismo a lo largo del tiempo y algunas clasificaciones de las diferentes apps encontradas. Con una de estas clasificaciones obtenida para apps relacionadas con el corazón, se encontró un tipo de app muy interesante pero con un desarrollo limitado. Se trata de una app para la autogestión de enfermedades y condiciones del corazón. Se vio mucho potencial y se decidió crear una app con este objetivo, denominada Heartkeeper.

Cuando se crea una app de mSalud hay que considerar varios aspectos, además de los técnicos. Es importante tener en cuenta la seguridad y la privacidad de manera acorde con los datos de los usuarios tratados en la app. Dicha app debe ser testada no solo técnicamente sino también desde el punto de vista de la Calidad de Experiencia (*Quality of Experience,* QoE) del usuario y la conformidad con las recomendaciones del sistema operativo elegido. Finalmente, es recomendado realizar un análisis ex-ante del impacto económico del uso de la app en una región. Todas estas cuestiones fueron planteadas e investigadas, y la experiencia y lecciones aprendidas son compartidas con la comunidad académica y los desarrolladores, que pueden obtener una ventaja añadida con este trabajo.

Abstract

In the last years, Internet has been reaching almost every zone in the world and new technologies have been discovered and created, especially in mobile telecommunications. These technologies have propitiated the development and fast expansion of mobile devices such as smartphones and tablets, and, with these devices, a new software industry: the mobile apps industry. Currently, there are apps for every aspect of life, videogames, educational, productivity apps, and, of course, apps focused on health care. These apps related to health care are part of what is called mobile health or mHealth, defined by the World Health Organization as "*medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices*". Hence, the objective of mHealth applications and systems is to fight against conditions and diseases that undermine the health of the patients trying to diagnose, treat or relieve them.

This work has two main objectives. The first is to perform a review of the existing mobile applications focused on non-communicable diseases or conditions, especially in the field of cardiology. This review was focused on the most prevalent conditions, the diseases that are leading causes of death and heart diseases. This was complemented with a review of Mobile Decision Support Systems (MDSS). The second objective is the design, creation and development of an innovative mobile application in the field of cardiology in order to fill a gap found in the previous review. In order to achieve that goal, several researches were performed to solve the problems encountered. The experience learned is shared with researchers and developers in order to help them in the process of developing mHealth apps.

The review was performed in different stages and it was done in both academic and commercial systems and databases, with a number of requisites. Several results were obtained, such as the distribution of work done in the different diseases, the evolution of this work along the years and some classifications of the different apps found. With one of these classifications obtained for heart related apps, a very interesting type with limited research was found. It was an app for the self-management of heart diseases and conditions. It was catalogued with high potential by the authors, who decided to create an app with this objective named Heartkeeper.

Several aspects should be considered when creating a mHealth app, apart from the technical issues. It is important to consider security and privacy aspects according to the users' data treated in the app. The app should be tested not only in the technical aspects, but also from the point of view of the Quality of Experience (QoE) from the users and the compliance with the guidelines for the operating system selected. Finally, it is recommended to perform an ex-ante analysis of the economic impact of the use of the app in a region. All these issues were faced and researched, and the experience and lessons learned are shared with the academic community and also with developers, who can obtain special advantage from this work.

1. Introduction

1.1. Background

Since the creation and expansion of the Internet, new technologies have been created in every facet of life [1]. As a result, an incredible boost of the mobile technologies has been produced in the last decade, being created many new wireless communication technologies. Some examples are mobile telecommunication networks (2.5G, 3G, 4G, HSPA+), Wireless Local Area Networks (WLAN), Wireless Personal Area Networks (WPAN) including Bluetooth and ZigBee, Wireless Body Area Networks (WBAN), Wireless Sensor Networks (WSN), Radio-frequency Identification (RFID), and Worldwide Interoperability for Microwave Access (WiMAX) [2-7].

These mobile communications, in combination with other technologies have propitiated the fast expansion of mobile devices such as smartphones and tablets, especially in developed and under-development countries. Currently there are more than 1 billion smartphone units worldwide [8]. Taking into account also tablets, there are more than 1.8 billion of global users [9] and it is expected to surpass 2 billion in 2016, which is a quarter of the world population [10]. Besides, the number of users of mobile devices surpassed the users of desktop devices at the end of 2013, which is a clear sign of the users' preferences of mobile devices over desktop systems [9]. To see this evolution, Figure 1 shows the number of smartphones sold to end users worldwide from 2007 to 2014.

This amazing growth of the number of users has propitiated the creation of a new branch in the software industry: the mobile applications or apps, understood as programs for smartphones and tablets which can be downloaded in the device directly from a commercial store. This industry has grown at the pace of smartphone sales and as of July 2014 there were 3.17 million apps [12] in the most common commercial stores. Figure 2 shows these numbers for each different store. As it can be seen, Google Play and Apple App Store have many more apps than the rest and, besides, the operating systems these stores use, Android and iOS respectively, have the majority of the market share: 76.6% for Android and 19.7% for iOS as July 2014 [13].

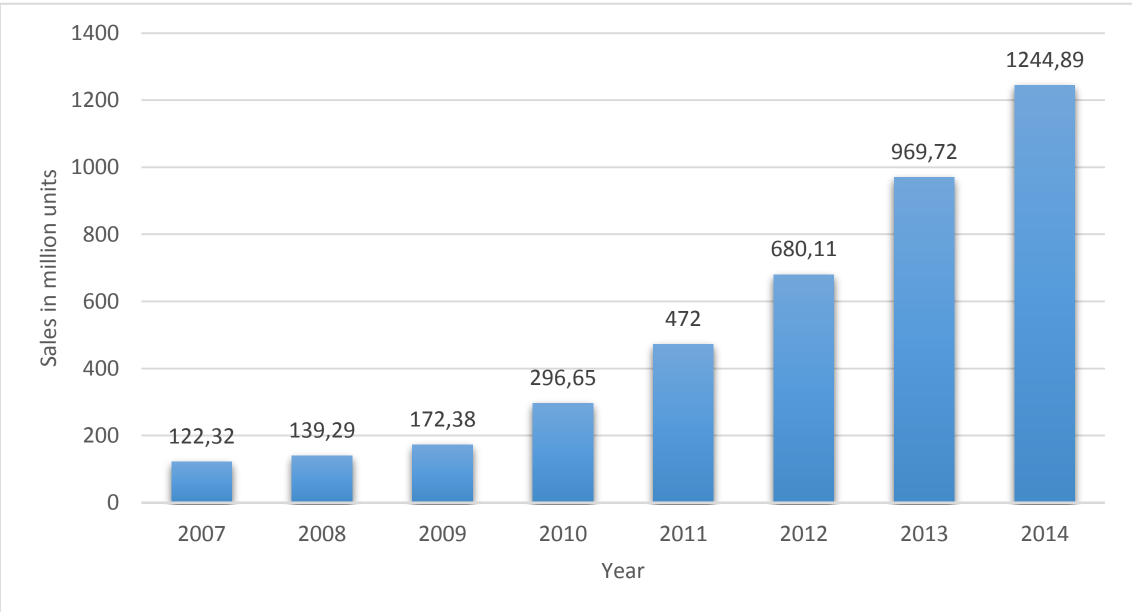


Figure 1. Number of smartphones sold to end users worldwide from 2007 to 2014. Source: [11]

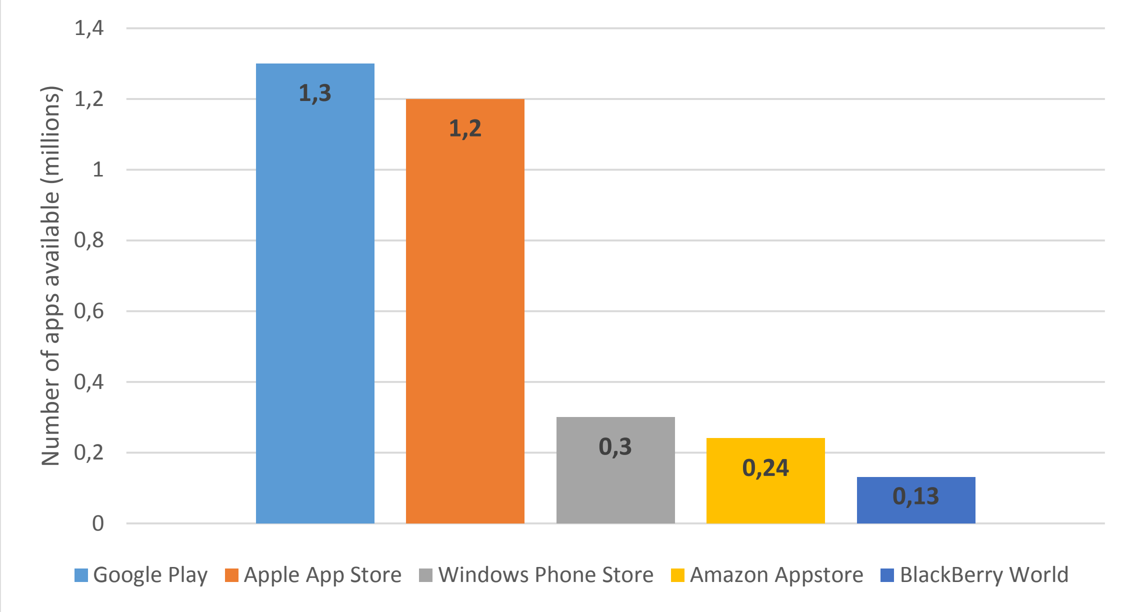


Figure 2. Number of apps available in leading app stores as of July 2014. Source: [12]

These apps have different purposes and can be enclosed in different categories: games, education, business, lifestyle, travel, etc. There are also apps for health care and medical apps. In fact, health and fitness apps are 2.74% of the totality of apps while the medical apps are 2.08% [14]. As of June 2014, there were almost 43,700 medical apps available only in the Apple store and their number is growing each day [15].

All these type of apps focused on health care are part of the mHealth or mobile health, which was defined by the Global Observatory for eHealth (GOe) of the World Health Organization (WHO) as "*medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices*" [16]. Although PDAs experienced a boom in the 1990s and early 2000s, they have been replaced by smartphones and tablets, which are much more extended, as seen before. Hence, mobile health can be seen as systems (hardware, software or both combined) that use the mobile technologies mentioned for providing or improving the health care of the users. mHealth is more than mobile apps for mobile devices. Its potential is rather well documented and there are a number of studies related [17-20]. For example, there are systems for teleconsulting, for managing electronic medical records, for accessing to information about medications, for continuous monitoring of vital signs or those with educational resources for specific diseases, diagnosis, treatment and prevention.

With this framework, it is normal that the mobile technology and applications are now used for health care, since health is an essential aspect of every individual. The last scientific and medical advances have caused an elderly population and long-term survival of people who suffer chronic diseases, thanks to modern treatments and therapies. This has increased not only the life expectancy but also the quality of life expectation of health care consumers [21]. In 2008, the WHO estimated a total of 56.8 million deaths, of which only 5.1 million were produced by injuries. The rest were caused by communicable disease, maternal and perinatal conditions as well as nutritional deficiencies (15.6 million deaths), and non-communicable conditions (36.1 million deaths) [22]. These diseases are getting more common thanks to the mentioned high life expectancy, so they have to be seriously considered. Nevertheless, attention should be focused not only on these diseases and conditions that can cause death, but also on those that can produce a disability or loss of health. In this context, it is essential to know the prevalence of an illness, known as the number of people who have the condition at any moment [23].

Of all the non-communicable diseases, the leading causes of death are cardiovascular diseases (CVDs), with a total of 17.5 million casualties in 2012, which means 31% of all deaths worldwide [24]. Besides, the predictions are not better: more than 23 million people are estimated to die annually from CVDs by 2030 [25]. Among them, heart-related diseases have special impact in mortality. For instance, ischemic heart disease is especially dangerous, since it is responsible for 7.4 million deaths only in 2012. In addition, other heart diseases suppose a significant number of deaths, such as inflammatory heart disease or hypertensive heart disease.

It is very clarifying the fact that more people decease of heart malfunction than of AIDS and all cancers combined. The number of disabilities these diseases cause is also very important. Only ischemic heart disease caused 62,587 million Disability-Adjusted Life Years (DALYs) [26]. All these data presented imply colossal costs to the economy of the countries: only in the United States these diseases supposed a total of US$320.1 billion in 2011, including health expenditures and lost productivity [27].

In light of these data, it is totally necessary to reduce the numbers of deaths and DALYs that CVDS and especially heart diseases cause, not only in health care premises such as primary health care facilities, but also in the homes and workplaces of patients. So, it seems that the mobile technologies and the mHealth applications mentioned are the perfect tool for meeting this objective, with special allusion to the apps focused on cardiology and heart conditions available in the commercial stores or under-development.

1.2. Objective

The main aim of this work is to research about mobile health systems and apps related to non-communicable or chronic diseases, especially in the field of cardiology. In order to do so, this work is composed by two different parts with several studies in each one.

The objective of the first part of the work is to obtain the state of the art of the mHealth apps for several diseases by performing systematic reviews. Four different reviews are performed, but all of them connected by the estimations and documents of the WHO [23]. The first review [28-29][A1.1-A1.2] studies the existing applications for mobile devices exclusively dedicated to the eight most prevalent health conditions by the last update of the document Global Burden of Disease of the WHO [23]. These conditions are Iron-Deficiency Anaemia (IDA), hearing loss, migraine, low vision, asthma, diabetes mellitus, osteoarthritis (OA), and unipolar depressive disorders.

The second review [30][A1.3] studies the amount of research and mobile applications dedicated to the diseases and conditions that are the leading causes of mortality according to the WHO, grouped by different income regions. These are ischemic heart disease; stroke and other cerebrovascular diseases; lower respiratory infections; chronic obstructive pulmonary disease; diarrheal diseases; HIV/AIDS; trachea, bronchus, and lung cancers; malaria; and Alzheimer disease and other dementias.

Since it was seen that CVDs and especially heart diseases are the deadliest and that also cause many disabilities, the third state of the art review [31][A1.4] is focused on these heart diseases, studying the literature on mobile systems and applications available, as well as the apps related to cardiology from the leading app stores, Google Play and Apple App Store.

The last review [32][A1.5] focuses on the mobile clinical decision support systems and applications in order to know the state of the art of these systems, whose function is to link health observations with knowledge in order to support the decisions by health professionals for improved health care. The methods used for all these systematic reviews are the same: two reviews are done in each one, a literature review in academic databases and systems (IEEE Xplore, Scopus, PubMed, Web of Knowledge) and a review in the most important commercial stores (mainly in Google play and App Store).

Once known the state of the art of the mobile apps for the deadliest and the most prevalent diseases, with a thorough study in apps related to cardiology and heart diseases, and the decision support apps, a whole knowledge and classification of the currently available heart related apps are obtained. As a result, some types of apps are missing, such as apps for the self-management of heart conditions by the own patients. Hence, the next section of this work is to design and develop an app that fills this gap found in the market and performs the function mentioned. This app is named Heartkeeper (previously named Cardiomanager, as it is stated in some studies) and is designed for Android. Additionally, during the development of Heartkeeper [33][A1.6], different researches in mobile health with relation to this development are performed.

A tool for measuring the users' Quality of Experience (QoE) of mHealth applications is created in order to improve the quality of the existing apps and the ones to be released [34][A1.7]. This tool uses the Likert scale from 1 to 5 and it is applied to Heartkeeper (once finished) in order to assess its QoE obtained from its own users. Another tool for measuring the compliance of Heartkeeper with Android guidelines created by Cruz Zapata et al. (2014) is also applied to the app [35]. With the application of these two tools, Heartkeeper is tested and the results are presented in other study [A1.8].

Since clinical data from the patients is very sensitive, it is important to use mechanisms and techniques to assure the privacy and security of this information. Hence, a study of these topics in mobile health applications was performed when doubts related to security and privacy arose during the development of Heartkeeper [36][A1.9]. It consists of three parts: a study of the existing laws regulating these aspects in two of the most developed zones: European Union (EU) and the United States of America (USA), a quick review of the academic literature related to this topic, and a proposal of some recommendations for developers in order to create mobile health applications that satisfy the current security and privacy legislation.

Finally, it is performed an ex-ante economic impact assessment and a cost-effectiveness analysis that the use of Heartkeeper by patients with Heart Failure (HF) would have in the Spanish community of Castile and Leon [37][A1.10]. With this study, it is possible to predict the costs savings that the introduction and use of Heartkeeper can suppose to the public health system of the region mentioned.

2. Methods

The methodology used in this work is different for each type of study performed. However, the methods used for any of the 4 reviews done [28-32][A1.1-A1.5] are practically the same with some variances. Generally, these methods include a deep literature review and a commercial apps review in the different app stores.

The methods used in the literature review were the following:

- A search of published papers is developed in several academic systems and databases. These systems are IEEE Xplore, Scopus, Web of Science (previously known as Web of Knowledge) and PubMed. In the first review, ScienceDirect is also used.
- The search words are completely related to the topic to study and are defined previously, but if the numbers of results obtained is too low, another combination of words are used until obtaining a significant number of results. These search strings are used only for metadata.
- The results are limited to a determined period, normally the last 10 years. In the last review this period is for 7 years.
- Specific eligibility criteria are followed. Common requisites were the following: the papers should be written in English, should be related to the topic to study and must include at least a relevant application or system related to the topic searched.
- For applying the criteria chosen, the title and the abstract of each paper is read. If relevant, it is included in the study; if repeated, it is dismissed; if there are doubts, the whole paper is read in order to include it or not in the study.

The methods used in the commercial reviews are similar to the ones for the literature reviews:

- The review is done in the most important app stores of mobile devices considering the market share of their operating systems. For the initial review Google Play, App Store, BlackBerry World, Windows Phone Apps+Games Store and Nokia's Ovi Store are considered. For the second review Ovi Store is not used and for the remaining two only Google Play and App Store are considered.
- The search words are normally the same of the literature review.
- The search in commercial stores is not limited by a period, so all the apps returned are considered.
- Similarly to the literature review, eligibility criteria are followed. The apps should be in English or in the native language of the authors (Spanish), designed for human health, not animal health, and focused on the disease or type of app searched. Those apps included in the categories of entertainment, games or music are dismissed. In addition to these common requisites, other are used depending on the review done.
- For including or not the app in the study, its title and its description in the store are read. If it is irrelevant for the study, or do not fulfil the established criteria it is dismissed.

The flow chart with the steps used for both types of reviews is shown in Figure 3. Additionally, in some cases, a classification of categories of apps or systems found in the literature and commercial reviews are performed or some papers or apps are selected in order to perform an in-depth analysis. To perform that, all the authors convey in order to analyse the relevant papers and apps included in the study and the classification or selection is done together with common agreement.

For the development of the tools for measuring the QoE of mHealth apps [34][A1.7], it is decided to use the metric Mean Opinion Score (MOS) as a subjective measure that quantifies the perceptual effect of different forms of degradation of the service from the point of view of the end-users [38]. The features measured by the tools are: content quality, security, use, availability, performance, appearance, learning curve and accuracy of the apps. These tools are developed with the collaboration of psychologists. For evaluating them, a sample of representative commercial apps from Google Play is chosen, since Google Play it the most used store [13], as mentioned. To conduct the evaluation a total of 28 physicians and 112 patients collaborate filling in the tools delivered. The results of these evaluations are introduced in the program IBM SPSS Statistics [39] in order to obtain statistics from the results.

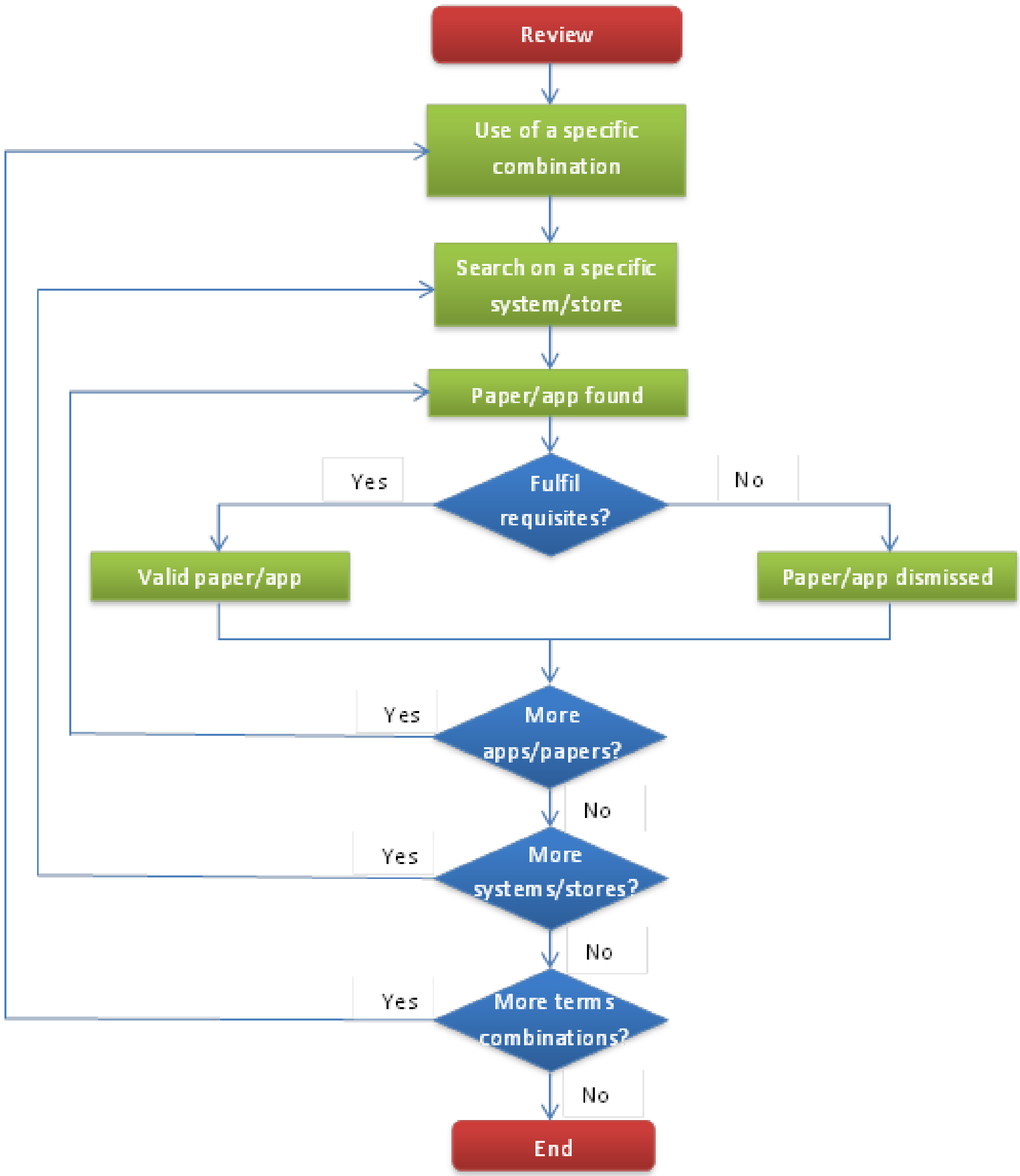


Figure 3. Flow chart of the methods used in the literature and commercial reviews (Source: [31][A1.4])

The methods used for obtaining the recommendations for developers in privacy and security [36][A1.9] are the following. Firstly, the security and privacy laws in mHealth in EU and USA are identified and carefully read in order to obtain the main points and acknowledge common aspects as well as main differences. Then a literature review of privacy and security aspects in apps is performed, including all the papers related to any mechanism or technique for ensuring privacy and/or security. The requisites and the methodology for this search are the same as the previous literature reviews. Finally, the results obtained in the previous parts of this research are used to create privacy and security recommendations for mHealth app developers.

For the design and implementation of Heartkeeper [33][A1.6], the methods used are the following. Based on the results obtained from the review of cardiology apps, it is decided to create an application for the self-management of heart diseases and conditions. The main reason of doing this is because only one app for this heart management is found in Google Play and the App Store. Additionally, the most common diseases are included in Heartkeeper: ischemic heart disease, valvular heart disease, hypertension, and auricular fibrillation. Other aspects that can influence the hearth health are also incorporated: the relations between heart and pregnancy, physical activity and diabetes. Heartkeeper was designed with three main sections:

- An informative section with medical information that will help the patients to understand their disease, its symptoms and its treatment; and a patient guide in order to inform the users about best practices, prohibitions and life style they should adopt in order to improve their condition.
- A section to record the user's activities (good and bad for their conditions) and health measurements in order to act in consequence with them. Examples of these activities are rehabilitation, physical activity or excesses (in alcohol or food intakes, for example), whereas typical measurements are blood pressure, glucose or cholesterol.
- A section for registering the users' medications and the hours that they should have them, offering the possibility to establish alarms to warn them. These intakes should be registered in order to create a daily record stored in the calendar.

For the implementation of Heartkeeper it is decided to develop it for Android, from version Android 2.3 (API 9), since it is the most extended mobile operating system [13], and the tool used for this is the Android Software Development Kit (SDK), which includes the Eclipse Integrated Development Environment (IDE) with built-in Android Development Tools (ADT). The lessons learned in the privacy and security research are applied to Heartkeeper. Hence, some features are included: a disclaimer with information about the app and the treatment of data is shown at first launch; the data is stored in the device rather than in a server or in the cloud in order to avoid external attacks; the most sensitive data are encrypted by a password-based algorithm that uses 256-bit Secure Hash Algorithm (SHA) techniques with random data input that adds more security in order to make those data inaccessible by intruders.

The interface is also carefully designed in order to obtain an app attractive to users, trying to do it simple and intuitive. The framework of Heartkeeper is shown in Figure 4.

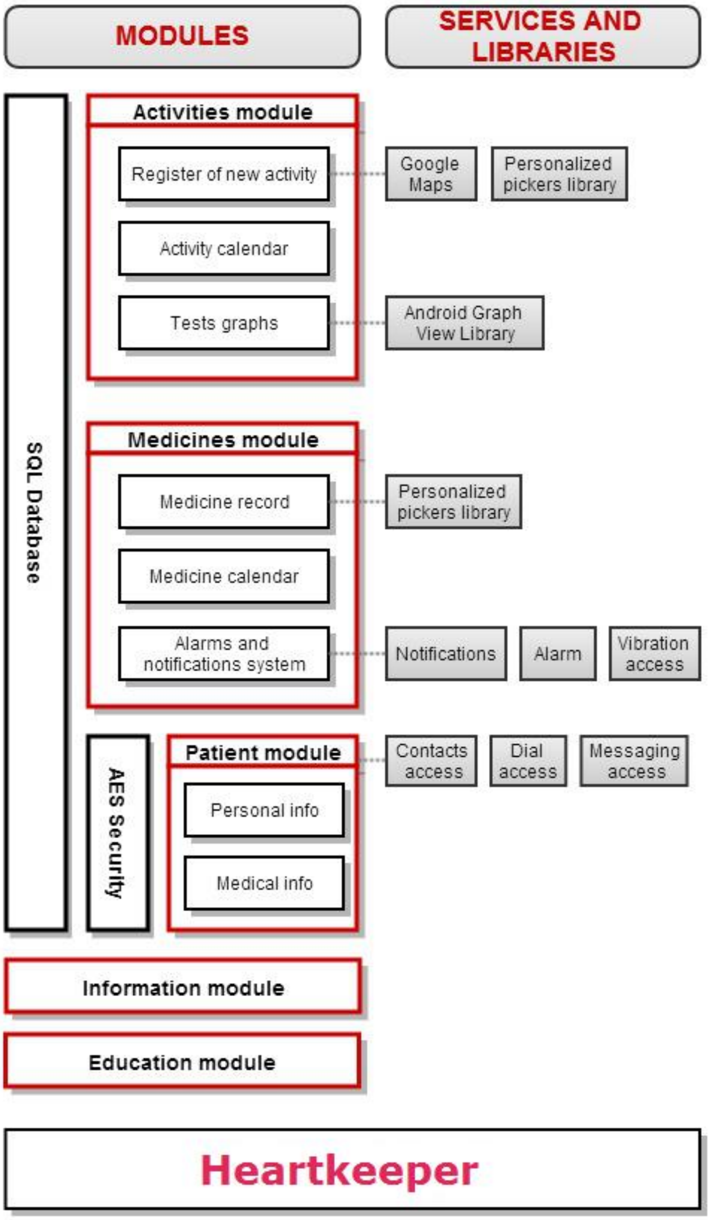


Figure 4. Framework of Heartkeeper (Source: [33][A1.6])

The validation of Heartkeeper is done by several methods. In an exhaustive testing phase all the operations permitted by the app are performed systematically in several devices with different screens (3.5, 5, 7 and 10.1 inches) in order to find errors and bugs and assure the correct behaviour of the app. The response times of the most time-consuming operations of Heartkeeper are also measured in the mentioned devices to check the speed of the app.

For measuring the compliance with Android guidelines [A1.8] a tool created by Cruz Zapata et al. (2014) [35] is used, a questionnaire shown in Table 1, which is based on the layers of web design style, behaviour and structure [40].

Each question is scored as follows: 1 point if the answer is "yes" for more than 70% of use cases of Heartkeeper, ½ point if the answer is positive for 30%-70% of use cases and 0 point if the answer is positive for less than 30% of use cases. These questions are responded directly by the authors together.

Table 1. Questionnaire for measuring the compliance with recommendations by Google

Q1. Style	
Q1. 1.	Is the writing style simple and informal and is the second person used to talk to the user?
Q1. 2.	Are pictures used to explain ideas?
Q1. 3.	Are pre-defined icons used for common actions?
Q1. 4.	Does the app adapt to both horizontal and vertical orientations?
Q2. Behaviour	
Q2. 1.	Are the user preferences learned over time?
Q2. 2.	Do the elements react to the user's gestures by changing color or illumination?
Q2. 3.	Are there confirming messages showing warning information related to actions that the user needs to consider?
Q2. 4.	Are there acknowledging messages to let users know that the action they have invoked has been completed?
Q2. 5.	Do long tasks show non-stationary activity indicators?
Q3. Structure	
Q3. 1.	Is the app loaded immediately without any splash screen or startup experience?
Q3. 2.	Is the login delayed to allow the user to use a particular functionality first?
Q3. 3.	Are suggested structure patterns used: action/tool bar, tab bar, spinner or navigation drawer?
Q3. 4.	Is the navigation consistent when moving between hierarchical screens?

The QoE of the users of Heartkeeper is also obtained using the survey created previously. From this tool, only two questions are not used since they were not relevant for Heartkeeper: the one related to the regular updates of the app (not included since no update has been done until obtaining the QoE), and the one related to the precision of the calculations done (not used since Heartkeeper does not perform any calculation). For obtaining the feedback of the users, the survey is accessible in a Google form [41] through a button included in the app, so every user could access it. The period for collecting responses was from October 2014 to February 2015, both included.

For the ex-ante economic impact assessment of Heartkeeper [37][A1.10], a population sample similar to the selected by Naveiro-Rilo et al. (2012) is used [42]. This sample consists of patients with documented chronic HF, seen through hospital discharge report done by a specialist or by the family doctor, and based on Framingham criteria diagnosis and additional examinations such as chest radiography, electrocardiogram and echocardiography. This sample belongs to the area of Valladolid, which has a population of more than 200,000 individuals over 39 years.

An anonymous census is elaborated with 2000 patients. The sample size is considered for estimating dichotomous variables with an overall precision for the health area of 4% and 95% confidence, in proportions of 50%. The result is a size of 630 patients. An economic evaluation type cost-effectiveness [43-44] is made on a structured Markov model, via a static deterministic hypothetical cohort with annual cycles and considering the clinical states shown in Figure 5.

The cost of the tool is estimated in 100 euros, 90 € for the mobile device with 10 € overhead, whereas the app is free. For the health care costs, the guide of costs of the Ministry of Health, Social Policy and Equality [45] is used. Data on HF incidence is obtained from the Statistics Central of the Ministry of Health, Social Policy and Equality [46-47]. Finally, the probabilities of death are estimated based on the age-specific mortality rate for 2011 published by the

National Statistics Institute [47-48]. The results of this analysis are calculated using the incremental cost-effectiveness ratio (ICER), expressed as cost per additional Quality-Adjusted Life Year (QALY) obtained. For the construction and the model analysis the software Tree Age Pro Suite 2009 is used.

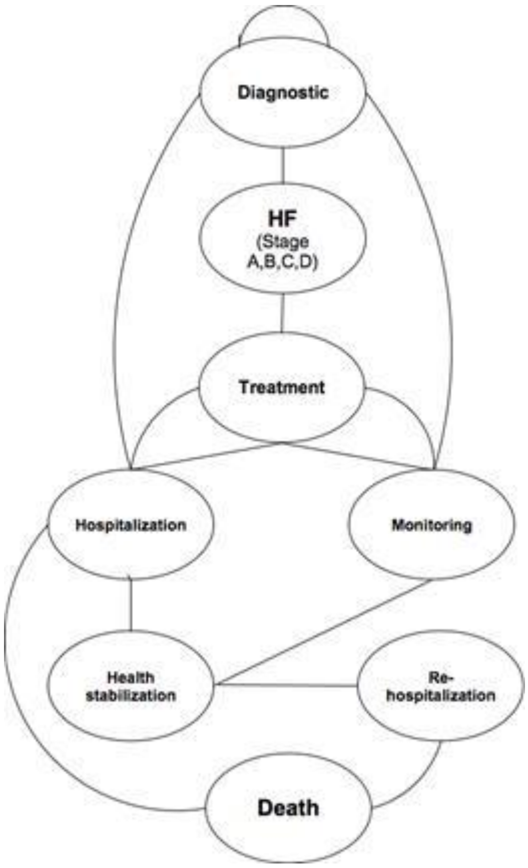


Figure 5. State diagram of the adapted Markov model (Source: [37][A1.10])

3. Results

In this section the main results of this work are presented, extracted from each study performed.

Firstly, the results obtained from the literature and the commercial review of the systems and applications for the most prevalent conditions [28-29][A1.1-A1.2] are presented in Table 2 and 3 respectively. The last column of both tables indicates the addition of all the matches obtained in all the systems for each disease. Table 3 indicates the number of relevant apps out of the total number of apps returned in each store. Besides, the results of diabetes and depression were divided into results for diabetes mellitus and diabetes in the first case, and depression and depressive disorders in the second.

Table 2. Results of the literature review of the applications for the most prevalent conditions

	IEEE	Scopus	ScienceDirect	WoK	PubMed	**Total**
Anaemia	2	3	0	1	1	**5**
Hearing loss	4	8	0	5	2	**9**
Migraine	2	2	0	1	1	**3**
Low vision	0	7	1	3	1	**9**
Asthma	8	29	1	25	16	**36**
Diabetes mellitus	16	112	5	79	53	**140**
OA	0	6	1	5	3	**6**
Depression	6	22	5	18	13	**32**

Table 3. Results of the commercial review of the apps for the most prevalent conditions

		Google Play	iTunes	BlackBerry	Windows Phone	Ovi Store	**Total**
Anemia		7/74	7/21	0/0	0/0	0/0	**14**
Hearing loss		17/42	32/37	0/0	3/5	-	**52**
Migraine		57/201	46/102	5/6	4/8	0/0	**112**
Low vision		33/43	30/46	0/0	1/1	-	**64**
Asthma		44/226	57/124	6/7	4/14	1/2	**112**
Diabetes	**Diabetes**	>1000	605	33	81	40	**>1759**
	Diabetes mellitus	19/67	17/21	0/0	2/3	15/40	**53**
OA		16/46	5/16	0/0	2/2	1/1	**24**
Depression	**Depression**	>1000	419	13	69	35	**>1536**
	Depressive disorders	1/5	0/0	0/0	0/0	-	**1**

Similarly, the outcomes from the literature and commercial review of the applications for the deadliest diseases [30][A1.3] are shown in Tables 4 and 5 respectively. These tables are similar to the Tables 2 and 3. The last row of Table 5 shows the total number of apps returned in each store.

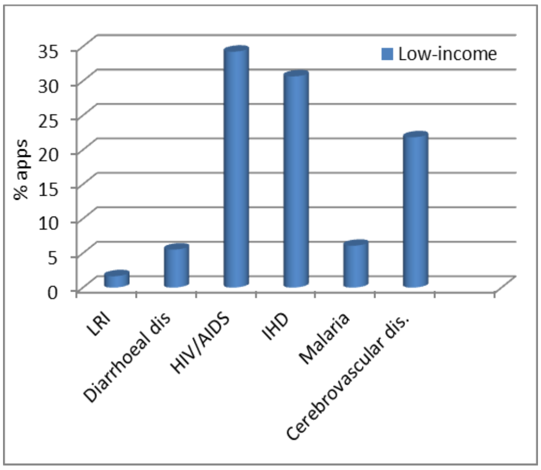
Figure 6 shows three graphs, each one for a different region (low-income, middle-income and high-income region), indicating the percentage of the number of apps found in the stores for each of the top 6 causes of death in each region, excluding the rest.

Table 4. Results of the literature review of the applications for the deadliest diseases

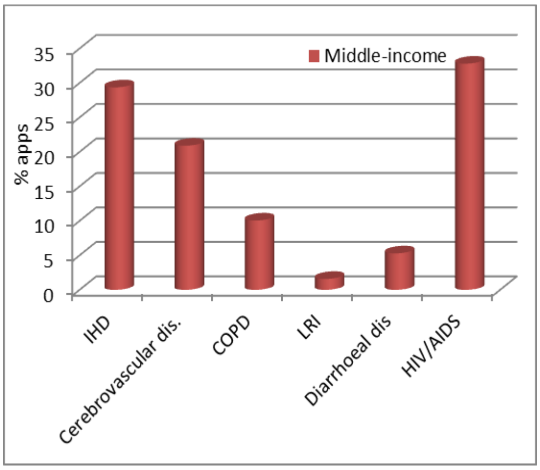
	IEEE	Scopus	Wok	PubMed	**Total**
LRI	5	11	5	2	**12**
Diarrhoeal diseases	0	2	0	0	**2**
HIV/AIDS	3	15	6	4	**18**
IHD	24	31	27	8	**49**
Malaria	1	4	2	2	**4**
Stroke and other cerebrovascular diseases	5	16	10	4	**19**
COPD	3	8	6	1	**10**
Trachea, bronchus, lung cancer	1	2	1	1	**2**
Alzheimer and other dementias	8	22	12	4	**24**

Table 5. Results of the commercial review of the apps for the deadliest diseases

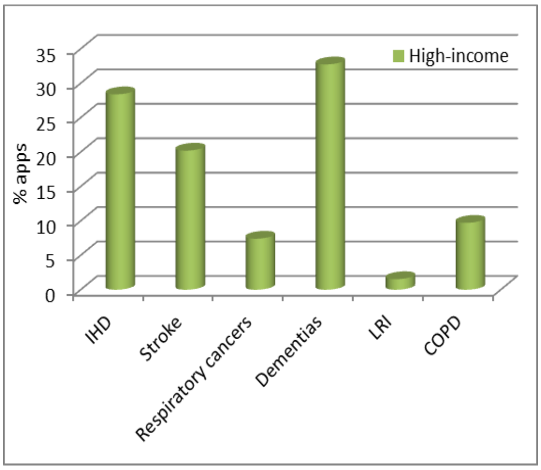
	Google play	iTunes	BlackBerry World	Windows Phone Store	**Total**
LRI	5/57	1/17	0/0	0/0	**6**
Diarrhoeal diseases	12/88	8/12	0/0	0/5	**20**
HIV/AIDS	54/238	56/121	7/8	7/19	**124**
IHD	60/249	44/79	3/4	4/21	**111**
Malaria	12/51	7/25	1/2	2/8	**22**
Stroke and other cerebrovascular diseases	27/>1000	45/530	4/46	3/105	**79**
	0/0	0/2	0/0	0/0	**0**
COPD	20/50	17/37	0/0	1/3	**38**
Trachea, bronchus, lung cancer	0/0	0/1	0/0	0/0	**0**
	0/1	0/0	0/0	0/0	**0**
	14/88	14/54	1/3	0/2	**29**
Alzheimer and other dementias	38/175	25/96	1/2	6/14	**70**
	32/185	23/70	0/0	3/10	**58**
Total apps per store	**274**	**240**	**17**	**26**	



(a)



(b)



(c)

Figure 6. Percentage of apps (%) related to the top 6 causes of death of each different zone: (a) low-income zone, (b) middle-income zone and (c) high income zone (Source: [30][A1.6])

From the review of mobile applications and systems related to cardiology [31][A1.4], a total of 406 papers and 710 apps are found, 439 available for iOS and 271 for Android. Table 6 shows the classification of the relevant papers by their content, which also shows the number of articles for each category. Similarly, Table 7 and Table 8 shows the classification of the apps found, sorted by their functions.

Table 6. Classification of the results of the literature review of mobile applications related to cardiology

Type of system/application	Articles
Vital signs monitoring system	55
ECG (Electrocardiography)/cardiac signal detection/classification algorithms	44
Heart monitoring system	37
ECG/Heart monitoring system trial/evaluation	28
Remote heart monitoring system	25
Heart monitoring system with alerts	17
Cardiac rehabilitation mobile system	16
ECG data transmission	14
Blood pressure measurement/monitor system	13
Remote management/monitoring of implanted pacemakers/cardiac devices	11
Teleconsultation system	10
Remote and local heart monitoring system	8
Exercising/sports related heart monitoring system	7
Innovative heart rate monitor	7
Arrhythmia detection system	7
Sensors evaluation/state of the art	6
Surveys/states of the art of cardiology systems	5
Heart rate & blood pressure monitoring system	5
Remote heart monitoring system with alerts	5
Atrial fibrillation detection system	5
Heart failure detection system	5
Phonocardiography mobile system	5
Remote and local heart monitoring system with alerts	4
Breath monitoring system	4
ECG data compression technique	4
Automatic music selector to maintain a target heart rate	4
Alerts and location of heart attacks	4
CPR instructions through mobile phone trial	4
CPR instructions/reminder through mobile phone	4
Applications for promotion of healthy behaviours	4
System for measuring/reducing stress	3
Personal lifestyle and health management system	3
Fetal heart monitoring system	3
ECG data encryption/authentication/privacy	3
Cardiac rehabilitation mobile system trial	3
Exercising/sports related heart monitoring system evaluation	3
Mobile medical applications for chronic diseases	2
Pocket-size images interpretation	2
First aid/resuscitation app evaluation	2
Apps for hypertension in smartphones	2
Emotional states detection through measuring heart rate differences	2
Weight control in high-risk heart failure population	2
Medications management	2
Telemetry-based system for monitoring rats' vital signs	1
Heart attack self-test app	1
Trial for comparing follow-up of hypertensive patients	1
Study about the correlation music-heart rate variability	1
App for improving Basic Life Support (BLS)	1
Non-invasive tissue classifier	1
Share of vital signs in a social network	1

Table 7. Classification of the apps related to cardiology of the commercial review (part 1)

Type of app	Number
Heart Rate Monitor	94
Algorithm/calculator/predictor	85
Informative guide	41
Educational ECG/Interpretation aid of ECG	37
News/journal	34
Blood pressure tracker	30
External devices heart rate monitor	22
CPR (Cardiopulmonary Resuscitation) instructions	21
Educational anatomy	17
Medicine students education	17
Guide/book	17
Health tips	17
Diagnosis & treatment guidelines	14
Echocardiography reference	14
Professionals & students education	14
Medicine exam preparation	13
General education	11
Diagnosis aid	10
Animated guide	9
Heart sounds reference	9
Blood pressure & heart rate monitor	9
Cardiology medical reference	8
Medical images reference	8
Catheter reference	8
Guide of professional commercial devices	7
Stethoscope/educational stethoscope	7
AED (Automated External Defibrillator) location	6
Professionals education	6
Clinical trials	6
ECG cases reference	5
Hypertension reference/guidelines	5
Procedures in emergency cases	5
Patients’ history/ECGs/images	4
Surgeon aid/training	4
Professionals connections, knowledge/cases share	4
Angiography reference/guide	4
Auscultation reference	4
Heart rate monitor for exercising	4
Fetal heart rate monitor/interpretation	4
Heart rate calculator	4
Ultrasound video reference	4
Resuscitation instructions/guide	4

Table 8. Classification of the apps related to cardiology of the commercial review (part 2)

Type of app	**Number**
Educational/explanations for patients	3
ECG sending	3
Log procedures	3
Diseases prevention guide	3
Heart rate monitor with external devices for exercising	3
Professionals guidelines	3
Audio reference	2
ECG signal transformer	2
Location of cardiac emergencies	2
Blood pressure measurement with external devices	2
CPR and AED instructions	2
Prescribing drugs	2
AED training	2
Pulse measurement aid	2
Hospitals	2
Instructions/training CPR & AED location	2
Perfusion reference	2
Arrhythmia reference	2
Acute coronary syndrome reference	2
Stent guide/reference	2
Prosthesis guidelines	1
Teleconsultation	1
Upload ECG from a commercial monitor	1
Medications reminder	1
Treatment guide	1
Stand-alone or with external device heart rate monitor	1
Auto-diagnosis	1
Cardiac rehabilitation guide	1
Anesthesia management	1
Social network	1
Atrial fibrillation guidelines	1
AED training with simulation of external device	1
Blood pressure prevention & treatment exercises	1
Condition management	1
Congenital heart defects reference	1
Clinical examination guide	1
Blood pressure measurement	1
Driving guidelines for cardiac patients	1

The last review done was related to mobile clinical decision support systems and applications [32][A1.5]. A total of 92 relevant papers and 192 commercial apps are found, 171 on Google play and 21 on the App Store. Table 9 shows the classification of these apps sorted by medical field.

Table 9. Classification of apps in the commercial review sorted by medical field

Medical field	Number
General medicine	47
Drugs information	16
Emergencies	12
Paediatrics	11
Cardiology	7
Oncology	7
Psychiatry/Mental health	7
HIV	6
Infectious diseases	6
Lab values	6
Neurology	6
Haematology	5
Cardiovascular	4
Dermatology/Wounds	4
Gynaecology	4
Radiation therapy/Radiology	4
Gastroenterology	3
Anaesthesia	3
Hepatitis	3
Nutrition	3
Orthopaedics	3
Respiratory system	3
Surgery	3
Urology	3
Diabetes	2
Geriatrics	2
Imaging	2
Albuminuria	1
Day time somnolence	1
Dysanatremia	1
Endocrinology	1
Hospital	1
Insomnia	1
Nephrology	1
News/Research	1
Ophthalmology	1
Sclerosis	1

Before initiating the process of designing Heartkeeper, a tool for measuring the QoE of mHealth applications [34][A1.7] is created. This tool is a survey that uses the Likert scale with the following values: 1. Strongly disagree, 2. Disagree, 3. Neither agree nor disagree, 5 Strongly agree [49]. It is presented in Table 10. This tool is tested with 13 different mHealth applications available in Google play, obtaining satisfactory results. Besides, another tool for not finishes apps is also designed considering only its content quality, which can be seen in Table 11.

Table 10. Survey to measure the QoE of finished mHealth apps

CONTENT QUALITY		
1	Does it make the function that you expected?	1 2 3 4 5
2	Can you do the same without the application?	1 2 3 4 5
3	Does the application receive updates regularly?	1 2 3 4 5
4	Do you think the data are reliable?	1 2 3 4 5
5	Can you identify with this application health problems?	1 2 3 4 5
6	Do you have possibility to send information about your status to your doctor?	1 2 3 4 5
7	Do you have better quality of life by using this application?	1 2 3 4 5
SECURITY		
8	Do you think that this application has appropriate security methods to protect data that are introduced?	1 2 3 4 5
9	Do you think that the data obtained with this application are sufficiently protected?	1 2 3 4 5
EASE OF USE		
10	Do you find what you need?	1 2 3 4 5
11	Do you think that the traditional method used so far is more difficult or does not exist?	1 2 3 4 5
12	Is this application useful for monitoring the disease?	1 2 3 4 5
AVAILABILITY		
13	Do you have the guarantee of access to the application and its data at any time?	1 2 3 4 5
PERFORMANCE		
14	Do you think you might have a more optimized performance?	1 2 3 4 5
15	Do you find some kind of error or problem while using the application?	1 2 3 4 5
APPEARANCE		
16	Do you find adequate the appearance of this application?	1 2 3 4 5
17	Would you change or add something from this application?	1 2 3 4 5
LEARNING		
18	Do you think that the time for learning the use of the application is appropriate?	1 2 3 4 5
PRECISION		
19	Do you think the calculations done by this application are correct?	1 2 3 4 5

Table 11. Survey to measure the QoE of not finished mHealth applications (research)

CONTENT QUALITY		
1	Would you use the app if developed?	1 2 3 4 5
2	Do you think that in the future it can be useful to society?	1 2 3 4 5
3	Do you think it will improve the quality of life of the users?	1 2 3 4 5
4	Will this future application help in treating diseases?	1 2 3 4 5

The most interesting results of the study of the privacy and security aspects in mobile health apps [36][A1.9] in the EU and the EEUU are shown in Table 12 and Table 13. There are two main laws that regulate these issues, which are the EU Data Protection Directive 95/46/EC from 1995 and the American Health Insurance Portability and Accountability Act (HIPAA) from 1996. Table 12 shows a summary of the most restrictive points of these laws, sorted by different requirements, whereas Table 13 gathers some recommendations for app developers in order to guarantee the privacy and security of the users' information.

Table 12. Laws requisites regarding privacy and security in mHealth applications

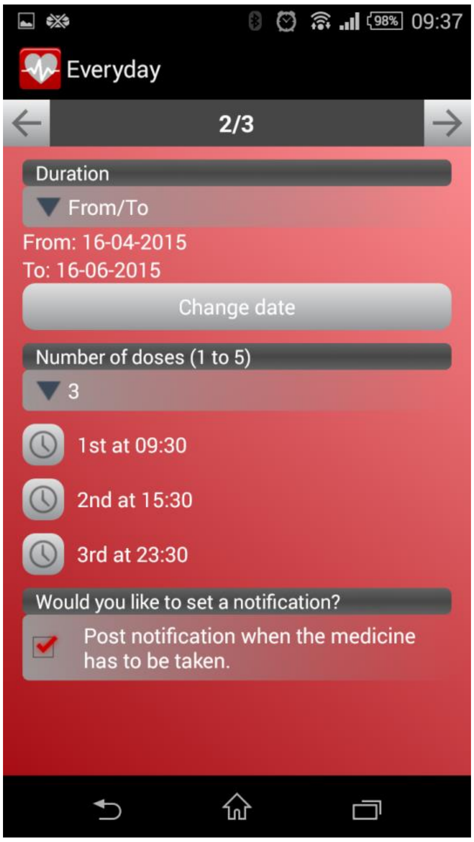
Cover data	The data that must be covered are that information that can be used to identify a person. It includes ID numbers, physical, physiological, mental, economic, genetic, social, medical, cultural factors regarding to the past, present or future of the patient.
Information requirements	Before providing their Personal Health Information (PHI), users must be informed about the identity of the person/entity that will use the PHI, the purposes of the collecting, the entity's privacy practices, whether the provision is compulsory or voluntary, the rights they have to access/modify the data and a contact method for more information or complaints. This information must be given directly to a parent or legal tutor in case of children under 13.
Consent requirements	The user/patient's consent to the data collecting must be obtained by the entity, when this collecting can not be justified by a statutory ground. The entity is enhanced to obtain this consent written. In the case of children under 13, they can not consent their data collection, being their parents or legal tutors the ones to do this.
Data retention	Generally, PHI should be kept only the necessary time for the purpose that was collected and must be erased once the purpose is reached. Entities must also include a clear data retention policy as part of their security procedures.
Security	The entities are required to implement and maintain appropriate technical, administrative, physical and organizational security measures to protect PHI from accidental or unlawful loss and unauthorized access or disclosure. Since health data is very sensitive, the security must be higher.
Breach notification obligations	In case of a personal data breach, the entities must notify it to the competent authority as well as the user whose data has been compromised without unreasonable delay, especially when the breach may have adversely affected to the user. In cases of massive breaches, the media should be also notified.
Data transfers	Entities need the users' consent to transfer their personal data to another entity or a third party, even when this transfer is necessary to complete one of the purposes of the data collecting, unless the transfer is allowed by law.

Heartkeeper can be considered the most important and tangible result of this work. It is the result of the process of development of a mobile application for the self-management of heart conditions and diseases by the own patients [33][A1.6], and all the lessons learned in the previous studies has been considered. It is designed for Android and Figure 7 shows some screenshots.

Table 13. Security and privacy recommendations for mHealth applications

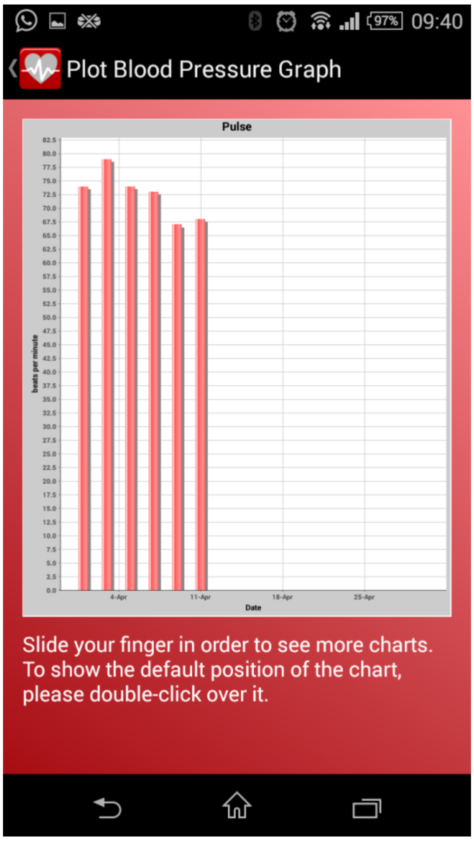
Property	Minimum requirements	Recommended requirements
Access control	The access control to the PHI must be patient-centric. The users should be able to allow or forbid access to their information at any moment.	It is preferable to create a role-based access, giving reading possibilities to some roles and adding limitations to other ones.
Authentication	The authentication must be done with a unique ID and a password only known by the user. This ID can be linked to a Public Key Infrastructure (PKI), preferable Rivest, Shamir and Adleman (RSA) system and/or a symmetric key used for encryption.	The password used must be complex, with at least seven characters and a combination of letters and numbers, including one capitalized letter and a special character. It is better to employ multifactor authentication to complement the ID/password identification when possible: using an item the user possesses (smart key) or a physical feature such as fingerprint.
Security and confidentiality	Use Advanced Encryption Standard (AES) to encrypt PHI. The cryptographic key used must have at least 128 bits. This method offers better encryption times than other techniques.	It is better to improve the security using a key of 192 or 256 bits.
Integrity	At least, a symmetric key-based authentication code must be used, for example AES.	A public key-based digital signature is preferred. Under no circumstances watermarking methods must be used with medical images since they can deteriorate the quality of them and even provoke bad diagnoses.
Inform patients	Before the collection and use of PHI, the app should present a privacy police informing the patients about the identity of the entity that will use the data, the purpose of the collection, the privacy methods used, the rights they have and a contact method. If the users accept this police they give their consent to the data collection. It must include a section for children under 13, requiring the consent of a legal tutor.	The policy should be easy to understand, concise and clear, since users are not fond of reading large legal documents in an app. It is highly recommended to leave the policy accessible for the user at any moment in the app.
Data transfer	Use Transport Layer Security (TLS) with 128-bit encryption methods. It is also possible to use Virtual Private Networks (VPNs).	It is preferable to use TLS with 256-bit encryption methods. It is also very recommendable to show an icon in the app notifying the transfer of data.
Data retention	The retention policy should be included in the privacy policy to inform the patients. The data should be kept only the necessary time for the initial purpose.	When the purpose is achieved, the PHI must be erased and the user should be notified. The entity should provide a mechanism to let the user check that the data has been deleted.
BANs communication	At least cryptographic methods must be used in securing the BSNs for authentication and key distribution. The mobile device (smartphone) can be identified and authenticated by its International Mobile Equipment Identity (IMEI) or its Subscriber Identity Module (SIM) card number.	Biometric patterns of the user can be utilized to encrypt and decrypt the symmetric key, which can facilitate the connection of the BSNs to the mobile device.
Breach notification	In case of a PHI breach, the competent authority as well as the user affected must be notified as soon as possible (1-3 days). The entity must help the user in order to relieve the consequences the breach may have caused.	It is important to compensate the user affected in order to compensate the possible damage done. In cases of breaches affecting a significant number of users, the media must be notified to inform of the problem.

(a) Main page of Heartkeeper



(b) Creation of a medication register

(c) Calendar activities



(d) Graph with the registers of pulse

Figure 7. Screenshots of Heartkeeper

As mentioned in the Methods section, Heartkeeper is tested in several ways. Hence, Table 14 shows the mean value of 10 measurements of the response times of the app in nanoseconds when performing specific actions.

The application of the tool for measuring the compliance of Heartkeeper to Android guidelines [A1.8] for each feature provides some results, presented in Figure 8, whereas the score averages obtained for each block with the tool for measuring the Heartkeeper users' QoE are shown in Figure 9.

For calculating the economic impact of the introduction of Heartkeeper in the region of Castile and Leon [37][A1.10] some previous calculations are needed. The characterization of the cost of a heart failure patient is made considering the report by the Ministry of Health Care, Social Policy and Equality [50]. Besides, costs are adjusted to 2011. The breakdown of costs associated to a heart failure patient is shown in Table 15. Considering this, the cost analysis of the two scenarios (without the introduction of Heartkeeper and with it) is shown in Table 16.

Table 14. Mean times (ns) of a total of 10 measurements of some operations with Heartkeeper

	Samsung GT-S6500	**Sony Xperia Z**	**Samsung Galaxy Tab 3**
Launch	211.826.000,24	110.205.078,20	56.673.023,80
Encryption	2.200.953.999,60	788.012.696,50	728.293.863,35
Decryption	2.319.032.666,40	708.050.537,40	650.942.188,80
Activity DB writing	49.139.777,80	100.712.367,34	72,071391,29
Activity DB reading	25.261.667,00	44.937.134,50	6.549.713,25
Medicines DB reading with 9 registers	15.697.500,95	14.175.415,20	10.826.702,42
Blood test graph drawing with 11 registers	122.416.667,26	258.453.369,65	59.414.637,15

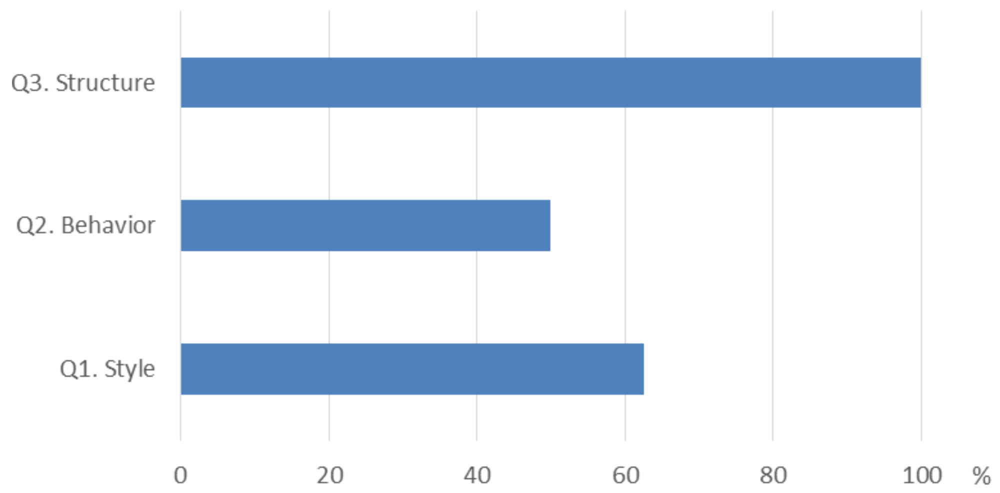


Figure 8. Average score obtained per block with the tool for measuring the compliance of Heartkeeper with Android guidelines (Source: [A1.8])

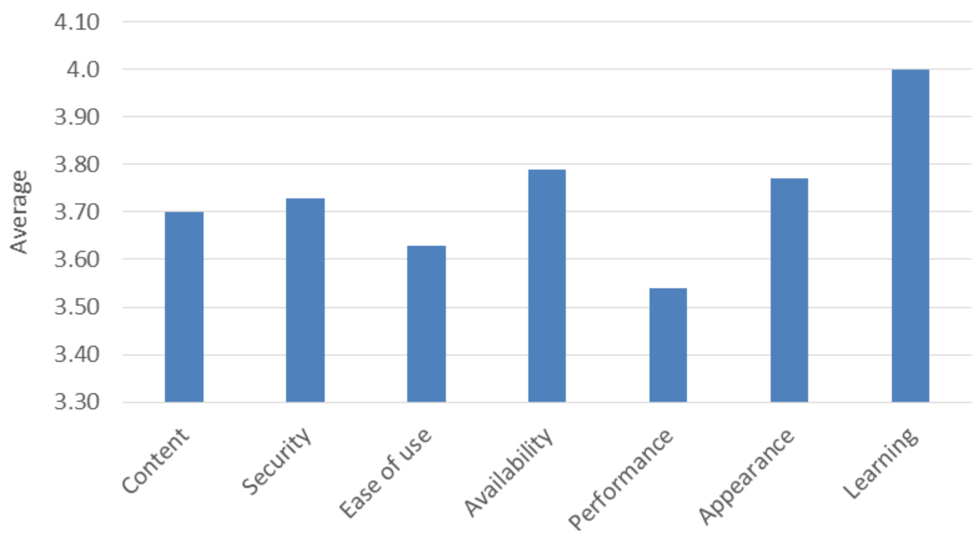


Figure 9. Score average obtained per block with the tool for measuring the Heartkeeper users' QoE (Source: [A1.8])

Table 15. Analysis of the cost of health states of the established Markov model

States	Unitary cost
Treatment	-
Hospitalization (including health stabilization)	13.889,79€
Outpatient care	1.413€
Re-entry	12.434,4€
Monitoring	577,92

Table 16. Ex-ante global impact analysis of the introduction of Heartkeeper for the management of HF

States	Without Heartkeeper	With Heartkeeper
Hospitalizations (including health stabilization)	13.889€	8.333€
Outpatient care	1.413€	1.413€
Re-entry	12.434€	9.256€
Monitoring and treatment	577	0
TOTAL per patient	**28.315€**	**19.012€**
TOTAL sample	**17.895.080€**	**12.015.584€**
ICER	**-**	**9.303**

According to [50], Heartkeeper is able to reduce the number of hospitalizations by 60% and the average stays by 73%. Additionally, the changes in the behaviour of the patients by the use of Heartkeeper mean a 33% reduction in the cost of management of the disease, which will be complemented with an increase in the efficiency in this management.

4. Discussion and Conclusions

In this section the most relevant conclusions extracted from the different studies of this work will be presented.

Some conclusions can be obtained from the literature and commercial review of the applications for the most prevalent conditions [28-29][A1.1-A1.2] and the leading causes of death [30][A1.3]. First of all, there are many more results returned in the commercial review than in the literature review, which means that the economic motivation is stronger than the research one. Secondly, comparing the number of apps available on each store, it is obvious that Android and iOS are the preferred operating systems by app developers. Windows Phone is the third in number of apps whereas Ovi Store (currently disappeared) and Blackberry World have a very small number of apps related to these conditions and diseases.

Focusing on the most prevalent conditions, a huge difference can be observed in the number of mobile applications depending on the considered condition. Hence, some conditions have more than 1000 apps, such as diabetes and depression while other varies in a range between 14 and 112 apps. Surprisingly, the most prevalent condition (IDA) is the second with less research and the first with less commercial apps. On the other hand, two of the less prevalent, such as diabetes and depression, are the most researched and commercially utilized. This can be explained by two reasons: the first is that diabetes and depression are common conditions of developed countries whereas IDA is common in underdeveloped zones; the second is that there is a big social conscience of diabetes and depression, much more than the social conscience of IDA. Following these findings, the four most prevalent conditions have less work than the remaining four, apart from OA.

Focusing on the deadliest diseases, there are two differentiated groups. On one hand, there are 4 diseases with the majority of work done, which are Alzheimer and other dementias, heart diseases, HIV/AIDS, and stroke and other cerebrovascular diseases. On the other hand, the rest of the diseases have much less work.

Comparing the number of work done for disease with the position in cause of death for the different zones, the following conclusions are obtained. The leading cause in high-income zones, heart diseases, is one of the most researched, which is logical since developers normally focus on typical diseases of developed zones [51]. However, the first and second causes of death in low-income countries, LRI and diarrheal diseases, have very little research. This is because they are not common (diarrheal diseases) in developed countries or there is no use of an app for them (LRI), so that their research is not worthwhile, in addition to the fact that in low-income zones (where diarrheal diseases and LRI are common) the technology for mobile devices is not widespread [52].

In contrast, HIV/AIDS is the opposing case. It is in the top 6 of low- and middle-income zones but not among the first causes of death in high-income countries, but it is the second disease with more work done. The reason is similar to what happened with diabetes and depression, HIV/AIDS is very popular and have a big social conscience not only in underdeveloped zones but also in in richer countries [53], so it has the attention of developers and the general population.

The most striking case is the one with trachea, bronchus and lung cancers. They are the third cause of death in high-income zones, but they have very few apps dedicated. The reason is not clear since cancer in general is a common matter with an enormous social conscience, specially these cancers since they are consequences of smoking [54]. Hence, developers have the opportunity to fill this empty space by creating apps for these types of cancer.

From the results obtained in the review of mobile applications related to cardiology [31][A1.4], several findings can be extracted. Focusing on the literature review, there are 198 papers related to heart monitoring systems including vital signs, which means almost half of all the papers found. This is a clear indicator that the most researched area is the linked to these heart monitoring systems.

From the commercial review, it can be seen a big distance between the first two positions in the classification (heart rate monitors and calculators) and the rest of the apps, when considering the number for each category. Contrasting with these types, there are others categories with very few apps, such as guides for cardiac rehabilitation and apps for the self-management of a heart condition of disease. For this reason, it was decided to design and develop a mobile app with this last purpose.

Some interesting findings can be obtained from the results of the review of mobile decision support systems [32][A1.5], especially from the commercial review. The most common field of these applications is general medicine, followed by others such as drugs prescribing, emergency services tasks and paediatrics. Focusing on the specialties, the ones with more apps are cardiology, oncology, psychiatry, neurology and infectious disease (especially HIV). As seen previously, these specialties involve some of the leading causes of death (ischemic heart disease, HIV/AIDS and trachea, bronchus and lung cancers), the most prevalent conditions (unipolar depressive disorders) and the most disabling diseases (Alzheimer, Parkinson). In addition, almost half of these apps are developed for medical specialists.

The QoE tools [34][A1.7] are created in the form of surveys because they are very common, useful and easy to answer. A similar thing occurs with Likert scale, so it is decided to use it as well in the creation of these tools. Besides, the use of Likert scale adds the possibility of introducing the data obtained in statistical programs. Another important aspect taken into account was the length of the surveys, since users can get tired or bored when answering too many questions. Hence, the tool is limited to 19 questions that can be completed in 1-2 minutes. Therefore, the main problem faced is to create a survey that covers every aspect of an app but with a limited length. The QoE tool is tested with a number of different types of mHealth applications and a total of 140 users. Among them, 127 are positive about the tool, so it is confirmed as useful for assessing the QoE of mHealth apps.

From the study of the privacy and security in mHealth apps [36][A1.9], some conclusions can be obtained. First of all, the laws that regulate these aspects were approved a long time ago (1995-1996), before the appearance of the mHealth technology. Therefore, these laws are based in obsolete technology only applicable to the eHealth field, so currently these laws are too open and too old and need to be renewed considering the current technologies and problems.

In Table 13 a short list with recommendations for developers is shown, in order to create apps that respect the users' privacy and security. It is suggested to apply the recommended requisites, not only the minimum requirements, but, in the end, developers must evaluate their apps and assess its impact in the security and privacy in order to use the necessary techniques to guarantee these issues. However, this is not a stand-alone guide; it should be seen as a complement of standards in security and privacy such as ISO/IEC 27001/2013 [56] about information security management and other related documents [57].

The production of the app Heartkeeper [33][A1.6] was done by performing all the steps needed to create a mobile app with guarantees. Firstly, a market research is performed in order to know the existing types of apps related to cardiology; then Heartkeeper is designed, with its functions and appearance; the implementation phase is next, with special consideration about the security and privacy of the app; finally, Heartkeeper is tested and validated to fix bugs and errors before its release in Google play. In this validation, it is seen that the launch of the app takes about 2 milliseconds in the worst case, which is much less than 2 seconds, as recommended [55]. The encryption/decryption of the user's personal data is the most time-consuming, about 2.3 seconds in the oldest device used and less than 1 second in newer devices. However, this operation is performed occasionally, so it can be concluded that Heartkeeper provides fast responses.

Heartkeeper can be improved by including the possibility to link external devices such as wearable or smart devices to it by wireless technologies (Bluetooth, NFC), in order to detect and take automatically measurements such as the blood pressure or heart rate, but this idea has not been performed yet since these external sensors are normally expensive and the majority of heart patients do not usually have them, so it was decided to develop a Minimum Viable Product (MVP) ready for its use by patients and leave the addition of this functionality for a later phase, when Heartkeeper is thoroughly evaluated and improved.

The application of the tool for the compliance with Android guidelines [A1.8] to Heartkeeper gives a score of 9, which is included in the High Quality Group, according to Table 17, extracted from [35]. This means that Heartkeeper is an app that obeys the recommendations for Android in many cases. However, the scores obtained for each block indicates that the structure of the app is perfect according to Android guidelines, but the style and behaviour of Heartkeeper need some improvements.

On the other hand, the application of the tool for measuring the users' QoE to Heartkeeper [A1.8] gives interesting conclusions. All the average scores obtained for each question are good, all over 3, which indicate the satisfactory QoE that Heartkeeper provides. The best valued aspects are its general appearance, its learning curve and the fact that the description in Google play corresponds to the reality. However, some aspects should be improved: a number of users indicated that they can do the functions of Heartkeeper using traditional methods, some sections in the app are difficult to find and its performance can be improved. This information is very valuable and these aspects will be revised in next updates of Heartkeeper.

Table 17. Quality Groups by the score obtained from the tool for measuring the compliance with Android guidelines

Score	**Quality Group**
12-13	Very High
8.5-11.5	High
5-8	Moderate
1.5-4.5	Low
0-1	Very Low

From the ex-ante economic evaluation [37][A1.10] the following conclusions are obtained. A saving for the Public Health Care System of Castile and Leon of approximately 6 million euros would be generated with a total investment of 63,000 €, which corresponds to a saving of 0.31% of the total health expenditure in this region [58]. Therefore, the introduction of Heartkeeper for the control of HF would have an impact not only in better management of the disease but also in generating savings of 33% of the total cost related to HF. This saving had an impact in the Health Care System and in the economy, because there are also gains in efficiency of the system.

As indicated, the main purpose of Heartkeeper is to help heart disease patients with the management of their diseases, which means an improvement in their quality of life. However, not only patients can benefit from it, but also providers and stakeholders. A company that develops health apps can obtain profits in several ways. They can sell their apps in the commercial stores and get paid for each download, but this method is only recommended when an app has been strongly promoted or when it has been adopted by an important institution or collective, such as physicians or nurses, who have enough power to oblige other groups to adopt that app. Either way, a powerful advertising marketing is needed, which can not be affordable by most companies. Other method to obtain profits from the health apps (and all types) is selling them for free but introducing ads in them, which can be specific ads if the target of the people who will use an app is well known [59-60]. The application of this way of commercialization is recommended initially in order to obtain a significant part of the market, and when the app is extended and commonly known, a premium version without advertising can be offered by a reasonable price. Hence, users are able to choose the most suitable version for each one. Of course there are other methods such as offering an app for free but with micropayments in it, or for a short period of time but when this period expires, the user needs to pay in order to continue using the app. However they are typical methods of aps containing video games so they are not recommended for a health app.

To sum up, the main result of this work is the mHealth app Heartkeeper, which is intellectually protected by the Spanish Patent and Trademark Office. During its designing, creation and development, some doubts arose and several researches were performed in order to find solutions to the problems found. As a result, important lessons were learned about mHealth applications and their development, so the authors wanted to present them to the academic community and, especially, to apps developers expecting that these findings will help them in their works. These experiences and results obtained from the design, development and evaluation of Heartkeeper were the following: the creation and evaluation of a tool for measuring the QoE of mHealth apps; the correct methods and implementations of the different phases of the whole process of the creation and evaluation of a health app; an study of the privacy and security systems commonly used in applications of this type, and a guideline with recommendation about these topics; and a study for measuring the ex-ante economic impact of the implementation of a mHealth app, which can be useful for app developers. In addition to these lessons learned and shared with the academic community, another important result obtained is the review of the state of the art developed for the mobile apps designed for the most critical diseases in terms of prevalence and mortality, with special attention to heart diseases.

5. Limitations and Future Lines

5.1. Limitations

This work presents a number of limitations. Focusing on the first part of the work, the study of the state of the art, the existing limitations are typical of these types of reviews. The process of extracting the data presented a significant risk of uncertainty. Occasionally, the inclusion of a paper or an app in the study is not easy because the text is not clear and it can be misunderstood. To avoid this possible error, we enhanced the assessment process with independent verification.

Some limitations were found and addressed (if possible) in the commercial reviews. Occasionally some searches did not return relevant results or return very few, such as the case of "ischemic heart disease", so other search strings similar to the used and related to the disease were used ("heart disease" for example). In other cases, there were too many results and a more specific definition of terms was needed in order to delimit them.

Another important limitation in the commercial review was the language used for the search strings, especially in the review of the deadliest diseases in different income zones. Ideally, at least the most important low- and middle-income countries languages should have been used to obtain all the apps developed in these languages. However, we only focused on the use of English, since it is the most extended and used worldwide. Additionally, apps whose summaries were in Spanish (the native language of the author) were included in the studies.

For the second part of the work, the development and evaluation of Heartkeeper, there are also some limitations. Focusing on the development, an important limitation is that Heartkeeper is only available for Android handheld devices, not for iOS devices such as iPhone and iPad. This fact limits its use in a significant number of mobile devices. Another limitation is that Heartkeeper is only available in Spanish and English, so people who do not dominate these languages can have problems when managing the app. Nevertheless, English is the language commonly used internationally, as mentioned, and Spanish is one of the languages most used, so this limitation is not critical. The last limitation of this part is that the development of Heartkeeper was done without direct contact with heart disease patients. However, the developers were constantly in contact with cardiologists, who were in turn in contact with patients and passed to the developers their knowledge and experience about the main problems that patients usually have. Hence, developers have an indirect contact with patients.

In the evaluation of the QoE of Heartkeeper, the number of users who respond (24 users) is very small, so the results can not be taken as definitive, but they can be illustrative about the potential of Heartkeeper. In a next work, a survey with approximately 100 users will be done in order to confirm the results obtained in this work.

5.2. Future lines

There are several future lines to do, all of them related to the evaluation and improving of Heartkeeper. The first future work is, as mentioned, to perform a more complete survey with a significant number of patients in order to corroborate the data obtained. It will be done with the supervision of their doctors in a clinical environment in order to control every possible aspect. This survey will be also complemented with another one with the purpose of proving the impact and efficacy of Heartkeeper in the health of its users. In fact, this survey is already being performed and it is currently accessible from the app [41].

An essential future work in order to spread Heartkeeper is making it available for other OS, especially for iOS. Hence, it is necessary the development of Heartkeeper for this OS. There are two possibilities: create a native app for iOS or create a hybrid app, which is an app developed using HTML and javascript with its container created for iOS. However, since Heartkeeper was created natively for Android, it will be also exported natively to iOS. Additionally and as mentioned in the previous section, Heartkeeper can be adapted in order to be connect to external wearable/smart devices using NFC or Bluetooth, enhancing the possibilities of the app and making easier the measures by the patients.

Finally, other future line is to compare Heartkeeper with other similar apps to demonstrate its relevance and to obtain interesting data from these comparisons. However, the main problem to do this line is that Heartkeeper is unique and this assessment will be done with other heart disease related apps whose main function will be possibly different to the purpose of Heartkeeper.

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Appendix

A.1. Publications included in this work

1. Mobile Health Applications for the Most Prevalent Conditions by the World Health Organization: Review and analysis. Published in Journal of Medical Internet Research in 1/6/2013.
2. Health Apps for the Most Prevalent Conditions. Conference paper presented in the XIII Meditarranean Conference on Medical and Biological Engineering and Computing (MEDICON 2013) celebrated in Seville (Spain) in 25-28 September 2013.
3. Comparison of Mobile Apps for the Leading Causes of Death Among Different Income Zones: A Review on Literature and Apps Stores. Published in Journal of Medical Internet Research in 9/1/14.
4. Mobile Apps in Cardiology: Review. Published in Journal of Medical Internet Research in 24/7/2013.
5. Mobile Clinical Decision Support Systems and Applications: A Literature and Commercial Review. Published in Journal of Medical Systems in 8/1/2014.
6. An Ubiquitous App for the Self-management of Heart Diseases: Implementation and Evaluation. Accepted in Health Informatics Journal (Version included: last review before acceptance).
7. Development and Evaluation of Tools for Measuring the Quality of Experience (QoE) in mHealth Applications. Published in Journal of Medical Systems in 7/9/2013.
8. Experiences and Results of Applying Tools for Assessing the Quality of a mHealth App Named Heartkeeper. Under review in Journal of Medical Systems since 23/3/2015. (Version included: initial submission).
9. Privacy and Security in Mobile Health Apps: A Review and Recommendations. Published in Journal of Medical Systems in 7/12/2014.
10. Economic impact assessment from the use of a mobile app for the self-management of heart diseases by patients with heart failure in a Spanish region. Published in Journal of Medical Systems in 4/7/2014.

Review

Mobile Health Applications for the Most Prevalent Conditions by the World Health Organization: Review and Analysis

Borja Martínez-Pérez*, MSc; Isabel de la Torre-Díez*, PhD; Miguel López-Coronado*, PhD

University of Valladolid, Department of Signal Theory and Communications, and Telematics Engineering., University of Valladolid, Valladolid, Spain

*all authors contributed equally

Corresponding Author:
Borja Martínez-Pérez, MSc
University of Valladolid
Department of Signal Theory and Communications, and Telematics Engineering
University of Valladolid
Paseo de Belén, 15
Valladolid, 47011
Spain
Phone: 34 983423000 ext 3703
Fax: 34 983423667
Email: borja.martinez@uva.es

Abstract

Background: New possibilities for mHealth have arisen by means of the latest advances in mobile communications and technologies. With more than 1 billion smartphones and 100 million tablets around the world, these devices can be a valuable tool in health care management. Every aid for health care is welcome and necessary as shown by the more than 50 million estimated deaths caused by illnesses or health conditions in 2008. Some of these conditions have additional importance depending on their prevalence.

Objective: To study the existing applications for mobile devices exclusively dedicated to the eight most prevalent health conditions by the latest update (2004) of the Global Burden of Disease (GBD) of the World Health Organization (WHO): iron-deficiency anemia, hearing loss, migraine, low vision, asthma, diabetes mellitus, osteoarthritis (OA), and unipolar depressive disorders.

Methods: Two reviews have been carried out. The first one is a review of mobile applications in published articles retrieved from the following systems: IEEE Xplore, Scopus, ScienceDirect, Web of Knowledge, and PubMed. The second review is carried out by searching the most important commercial app stores: Google play, iTunes, BlackBerry World, Windows Phone Apps+Games, and Nokia's Ovi store. Finally, two applications for each condition, one for each review, are selected for an in-depth analysis.

Results: Search queries up to April 2013 located 247 papers and more than 3673 apps related to the most prevalent conditions. The conditions in descending order by the number of applications found in literature are diabetes, asthma, depression, hearing loss, low vision, OA, anemia, and migraine. However when ordered by the number of commercial apps found, the list is diabetes, depression, migraine, asthma, low vision, hearing loss, OA, and anemia. Excluding OA from the former list, the four most prevalent conditions have fewer apps and research than the final four. Several results are extracted from the in-depth analysis: most of the apps are designed for monitoring, assisting, or informing about the condition. Typically an Internet connection is not required, and most of the apps are aimed for the general public and for nonclinical use. The preferred type of data visualization is text followed by charts and pictures. Assistive and monitoring apps are shown to be frequently used, whereas informative and educational apps are only occasionally used.

Conclusions: Distribution of work on mobile applications is not equal for the eight most prevalent conditions. Whereas some conditions such as diabetes and depression have an overwhelming number of apps and research, there is a lack of apps related to other conditions, such as anemia, hearing loss, or low vision, which must be filled.

(J Med Internet Res 2013;15(6):e120) doi:10.2196/jmir.2600

KEYWORDS

apps; mHealth; mobile applications; prevalent conditions; World Health Organization (WHO)

Introduction

Since the creation of the Internet, its massive use, especially in developed countries, has generated new forms of technology in almost every aspect of life [1]. One of these aspects is health care; Internet technologies have initiated major advances in telemedicine and telehealth, now present in every modern health care organization [2]. In the field of telehealth, eHealth has arisen as a paradigm involving the concepts of health, technology, and commerce, with commerce and technology as tools in the service of health [3]. Chang Liu et al (2011) perceive eHealth applications as the software applications that provide tools, processes, and communications in order to support electronic health care practice [4]. In addition to this, with the advent of wireless communications, there are no longer barriers of space and time between health care providers and patients [5]. The use of new wireless communications technology, such as mobile telecommunications networks (2.5G, 3G, 4G, HSPA+), Wireless Local Area Networks (WLAN), Wireless Personal Area Networks (WPAN) including Bluetooth and ZigBee, Wireless Body Area Network (WBAN), Wireless Sensor Networks (WSN), Radio-frequency Identification (RFID), and Worldwide Interoperability for Microwave Access (WiMAX), has greatly boosted telemedicine and eHealth [5-12].

In this context and thanks to these advances in communications, a new term arises: mHealth, a component of eHealth. The Global Observatory for eHealth (GOe) of the World Health Organization (WHO) defines mHealth or mobile health as "medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices" [13]. While new wireless technologies were being developed, new mobile devices were being created. In this way, PDAs, tablets, and smartphones appeared on the market. Although PDAs experienced a boom in the 1990s and early 2000s, they have been replaced by smartphones and tablets with new functions and utilities, which are common now in developed countries [4]. There are already more than 1.08 billion smartphones of a total of 5 billion mobile phones around the world, with 80% of the population having a mobile phone [14]. Regarding tablets, International Data Corporation (IDC) conducted research on their shipments showing 70.9 million shipments of tablets worldwide in 2011 and an estimated 117.1 million and 165.9 million in 2012 and 2013 respectively [15]. Thus, there is great opportunity for mHealth in using these mobile devices and, in fact, a significant number of mHealth applications have been already developed for these platforms.

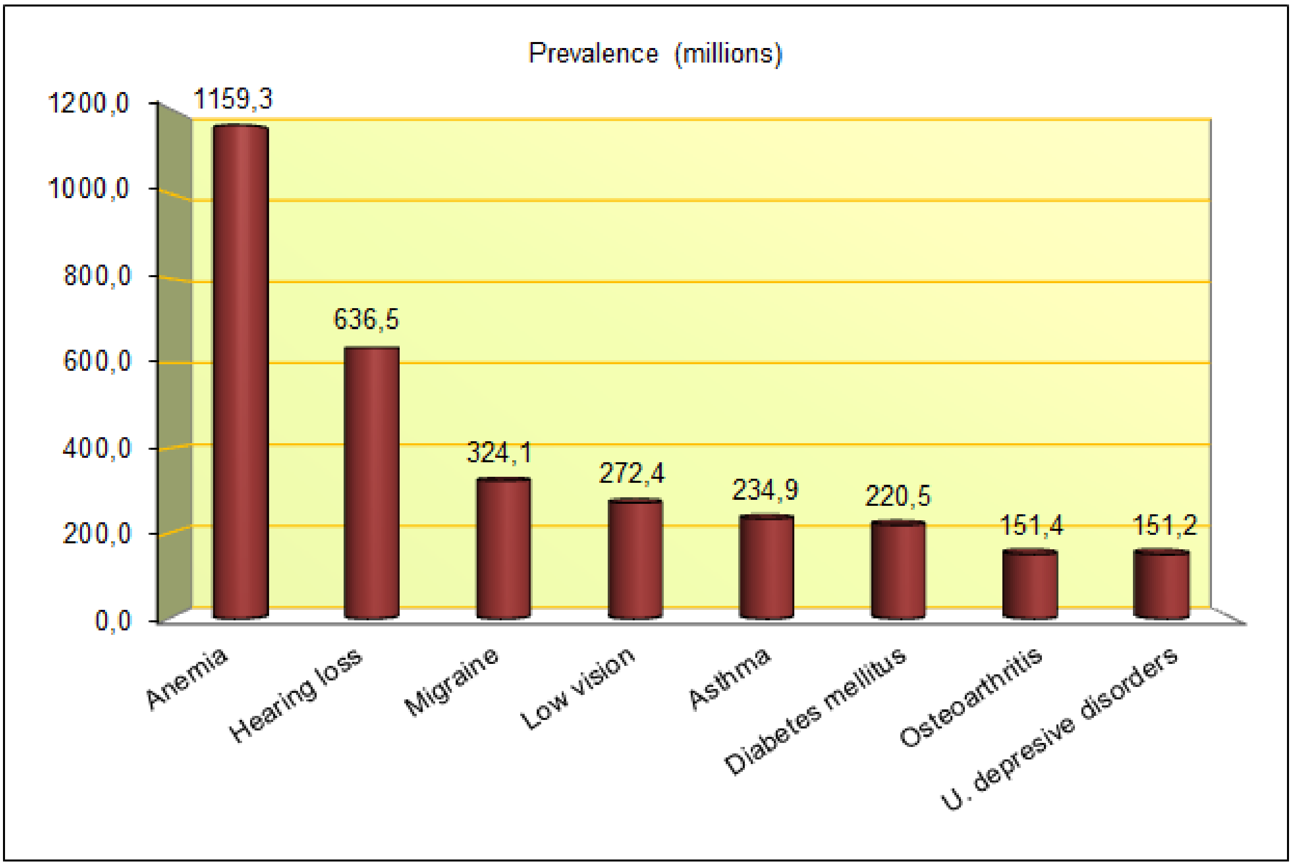
Telecommunications technology aside, it is clear that there is still a long way to go in defeating illness. In 2008, WHO estimated a total of 56.8 million deaths and only 5.1 million of them were caused by injuries. The rest were caused by communicable disease, maternal and perinatal conditions and nutritional deficiencies (15.6 million deaths), and noncommunicable conditions (36.1 million deaths) [16]. Nevertheless, attention should be focused not only on the diseases that cause death, but also the diseases or conditions that can cause a disability or loss of health. In 2004, 2.9% of the world's population were severely disabled, and 12.4% were moderately long-term disabled. In this context, it is essential to know the prevalence of an illness or condition, ie, the number of people who have the condition at any moment [17].

According to WHO's latest update (2004) of the Global Burden of Disease (GBD) [17], the most prevalent conditions are iron-deficiency anemia (IDA), hearing loss, migraine, low vision, asthma, diabetes mellitus, osteoarthritis (OA), and unipolar depressive disorder. The prevalence of each condition is shown in Figure 1. IDA represents 50% of the total cases of anemia (even though both terms are usually used interchangeably, they are not the same). The biggest percentage of affected can be found in underdeveloped and developing zones, in Africa, South East Asia, and Western Pacific, most of them women of reproductive age and children [18-20]. There are two types of hearing loss: moderate or greater hearing loss, which affect 275.7 million individuals, and mild hearing loss, with 360.8 million individuals [21-24]. Migraines are the most prevalent chronic neurological disorder in adults [25], with 11% of affected in Western countries [26-30].

The Global Data on visual impairment 2010 [31] indicates 246 million people with low vision and 39 million blind, equaling a total of 285 million people with any type of visual impairment [32-34]. Asthma is the most common chronic disease in childhood, and most asthma-related deaths take place in poor and developing countries [35-38]. It is estimated that 347 million people have diabetes mellitus [39], commonly named diabetes, but different from diabetes insipidus [40-55]. OA is the most prevalent musculoskeletal disease, and it is thought that 9.6% of men and 18% of women over 60 years have this condition [56-59]. Finally, there are more than 350 million individuals with any unipolar or bipolar depressive disorder [60-63].

To date, there are many published articles about types of wireless connections for mobile devices [8,9,64,65], articles about evaluations of apps for specific objectives [66-68], and reviews of apps of a determined device, software, or field [4,69,70], but there are not articles about the deadliest or the most prevalent conditions and diseases. Hence, the main aim of this paper is to study the existing applications for mobile devices exclusively dedicated to the eight most prevalent conditions [17] and to analyze a sample of the apps for each condition. The goal was to find the number of apps related to each condition, their common features, comparing the commercial ones with those used in research, and finding possible gaps in the development of these types of applications and whatever else might arise. For these purposes, a review has been done consisting of two steps: (1) research of published articles containing specific target strings, obtained by search queries in a number of databases, and (2) research of applications related to these conditions in mobile phone application stores.

Figure 1. The 8 most prevalent conditions by the WHO.



Methods

Two different reviews were developed. The first was a literature review and the second, a commercial applications review. Both were current as of April 2013. Finally, one app for each review and each condition was chosen for an in-depth analysis and comparison.

Literature Review

The literature review was developed on the following systems and databases: IEEE Xplore, Scopus, ScienceDirect, Web of Knowledge, and PubMed. After trying several combinations of words and expressions, the following combinations of terms were sought in the metadata field on each of these databases: “condition name” AND mobile AND (applications OR application OR apps OR app); m-health AND “condition name”; “mobile phone” AND “condition name”; smartphone AND “condition name”, where “condition name” is the name of each of the most prevalent conditions as they are issued by [17]. The results are limited to the last 10 years, from 2003 forward. The eligibility criteria were the following: publications not centered on applications using mobile phones or devices were dismissed, as were Web applications not optimized for mobile phone displays. Only papers published in English were studied. Papers on applications for several different diseases or conditions were rejected except for those with an important part of the application dedicated to the related condition. Some aspects were added due to the lack of sufficient results when executing some searches: instead of the search strings with “iron-deficiency anemia”, just “anemia” was used and the British term “anaemia”. Similarly, on IEEE Xplore, the search string with “anemia” was changed for the string anemia AND applications. Finally, the strings with “unipolar depressive disorders” were replaced by strings with “depressive disorder”, “depressive disorders”, “depressive episodes”, “depressive episode”, and “depression”.

Commercial Apps Review

The second review, the study of the commercial applications, was carried out on the application stores of the most popular smartphones brands [14,71] which are, in descending order of market share, Google play of Google Android [72], Apple iTunes [73], BlackBerry World of BlackBerry (previously RIM or Research In Motion Limited) [74], Windows Phone Apps+Games Store of Microsoft [75], and Nokia’s Ovi Store [76].

For this research, the name of the condition was searched (eg, “hearing loss”) and the eligibility criteria used were the following: applications not centered on the specific condition, not in English, or those included in the category of games, entertainment, or music were dismissed, as well as applications designed for pets or animals, and applications that are actually journals or magazines about the condition. During the search, the following issues were faced:

- On iTunes, apps for iPod and iPhone were separate from the ones for iPad, hence only apps for the first ones were searched, excluding the apps exclusively designed for the Apple tablet.
- Instead of “iron-deficiency anemia”, the word searched was “anemia” due to the lack of results.

- The Ovi search engine does not handle search phrases nor logical operators such as “AND” or “OR” correctly; therefore, the results for “hearing loss” and “low vision” were totally distorted and these results were not considered. In the case of “diabetes mellitus”, no problems were presented because both words are very specific about the condition.
- In the case of diabetes mellitus, the strings “diabetes mellitus” and “diabetes” were used.
- For “unipolar depressive disorders”, instead of this string, “depressive disorders” and “depression” were used because of the absence of results.
- There were some issues with Google play: when searching for “depression” and “diabetes”, the store indicated at least 1000 results but showed only 480. Google was asked about this conflict and the issue is still under investigation, but it is assumed that the first number is the correct one (>1000). In other cases such as the search for anemia, a certain number of results had been found but while exploring the results pages, the last pages (usually between one and three) were blank. Consequently, the number indicated by the store was different from the number of apps shown. In these cases, the number of apps shown was the one used.
- In the case of depression and diabetes, only the first 20 applications were analyzed due to the number of results; therefore, there is potential for completely new investigative work.

Eligibility Criteria for the In-Depth Analysis and Procedure

For the in-depth analysis, two applications were chosen for each condition: one obtained from the literature research and the other from the commercial apps review.

For the mobile applications found in publications, we decided to study the most recent paper on each condition taking into account only the year. In the case of two or more articles published in the same year, the final article was selected, considering the impact factor of the journal, where it is published (a conference article is considered at a lower level than journal articles), and its number of citations. If, again, two or more articles were published in the same journal and had the same number of citations, these papers were read and the most interesting according to the authors’ opinion was chosen. Articles about reviews of several apps or with insufficient information about the app were dismissed. If the app studied was available in stores, it was downloaded and personally tested on an iPhone 4 in the case of an iOS app or a Samsung Galaxy S SCL GT-I9003 in case of an Android app.

To evaluate the papers, after reading them individually, the authors convened to discuss opinions and fill in a table of features. For apps available on the market, one of the authors downloaded them for a joint evaluation at the meeting.

In the case of commercial apps, we preferred to choose apps from the same store for every condition and to use the store with the most extended software for smartphones. Therefore, Google play was selected because Android fulfilled this prerequisite [71]. For each condition, it was determined to opt for the first relevant free app with a rating, by users, of 3 or more stars, which Google play shows when searching by the condition sorted by popularity. In addition, another prerequisite was that the app had to be designed for patients, not for health care providers. This way, the most popular free app related to the condition with an evaluation over the mean and designed for the general public was analyzed. However, in the case of anemia, every result with a rating of 3 stars or more was aimed at caregivers; hence, we made an exception where the selected app was not intended for patients and did not fulfil all the previous requisites. The apps were tested on a Samsung Galaxy S SCL GT-I9003.

For the analysis of the commercial apps, the procedure followed was similar to the one developed with the research papers. The authors downloaded them on the mentioned mobile phone Samsung Galaxy S before meeting to study the apps together and complete the previously initiated table of features.

Results

Mobile Applications in Literature

The results of relevant papers on each database and each condition are shown in Table 1. The last row contains the number of different papers found for each condition.

Diabetes was the most investigated condition followed by asthma and depression. There is a significant gap between these three conditions and the rest since the next most investigated conditions were hearing loss and low vision with 9 different publications; this contrasts significantly with the 32 papers on depression. The order of the remaining conditions is: OA sixth, anemia seventh, and migraines last.

Mobile Applications in Stores

The findings on the commercial apps review are shown in Table 2. It shows the number of relevant applications out of the total number of applications found in each store. In the case of diabetes mellitus and depression, the results obtained were separated by “diabetes mellitus” and “diabetes” in the first case, and “depressive disorders” and “depression” in the second case. The last row shows the addition of all the applications located in all the stores for each condition, but it is important to note that some of the applications designed for a specific system were also designed for other systems. Thus, an application developed for Apple iOS can also be developed for Android or Windows Phone, for example.

These results illustrate that the store with most apps is Google play, followed closely by iTunes. The rest of the stores have fewer apps for the conditions searched. Windows Phone Apps+Games Store is the third in number of applications, and it seems that Ovi Store has more applications than BlackBerry World, although that is not clear because of the malfunction of its searching engine mentioned in the Methods section.

Comparing the number of conditions, it is obvious that the conditions with more applications are diabetes and depression. After these two, migraine and asthma are equal with 112 apps, followed by low vision, hearing loss, OA, and finally anemia.

Analysis of a Sample of Reference Apps

The papers and the commercial apps studied are summarized in Table 3 [77-97]. Figures 2 to 9 show snapshots from the commercial apps.

Tables 4 and 5 show the results from the analysis of some characteristics of the selected applications.

Table 1. Results of the literature review.

	Anemia	Hearing loss	Migraine	Low vision	Asthma	Diabetes mellitus	OA	Depression
IEEE	2	4	2	0	8	16	0	6
Scopus	3	8	2	7	29	112	6	22
ScienceDirect	0	0	0	1	1	5	1	5
WoK	1	5	1	3	25	79	5	18
PubMed	1	2	1	1	16	53	3	13
Total	5	9	3	9	36	140	6	32

Table 2. Results of the commercial apps review.

	Anemia	Hearing loss	Migraine	Low vision	Asthma	Diabetes		OA	Depression	
						Diabetes	Diabetes mellitus		Depression	Depressive disorders
Google Play	7/74	17/42	57/201	33/43	44/226	>1000	19/67	16/46	>1000	1/5
iTunes	7/21	32/37	46/102	30/46	57/124	605	17/21	5/16	419	0/0
BlackBerry	0/0	0/0	5/6	0/0	6/7	33	0/0	0/0	13	0/0
Windows	0/0	3/5	4/8	1/1	4/14	81	2/3	2/2	69	0/0
Ovi Store	0/0	-	0/0	-	1/2	40	15/40	1/1	35	-
Total	14	52	112	64	112	>1759	53	24	>1536	1

Table 3. Summary of the papers and commercial apps.

Health condition	Name of the paper/app	Description
Anemia	Activity and school attendance monitoring system for adolescents with Sickle cell disease [77]	Paper about the app SickleSAM, designed for Android, whose purpose is monitoring the school attendance of children affected by sickle cell disease, which usually causes anemia
	MD Series: Anemia - Free [78]	App for caregivers that provides some educational tools for the diagnosis and management of different types of anemia in adult patients
Hearing loss	Mobile software Apps support personalized-SRO and serial monitoring with results indicating early detection of hearing loss [79]	Article presenting a software application called OtoID used in a PDA connected to an audiometric unit for monitoring hearing change because of ototoxic medication and others factors, using a testing protocol called Sensitive Range for Ototoxicity (SRO)
	Hearing Tests [80]	App with a hearing test that uses sounds of different frequencies in order to check the user's hearing
Migraine	From a traditional behavioral management program to an mHealth app: Lessons learned in developing mHealth apps for existing health care programs [81]	Application for behavioral migraine management for iPad called iBMM, which can be used for learning relaxing and pain management techniques, tracking migraine attacks and contacting a counselor
	My Headache Log Pro [82]	App for tracking headache attacks by creating a diary of them, with its triggers, symptoms and medications used, and it also allows emailing these notes to the doctor
Low vision	Crowdsourcing subjective fashion advice using VizWiz: Challenges and opportunities [83]	The authors use VizWiz [84] for assisting people with vision impairments in matching garments and being dressed in a fashion way, with the advice of some volunteers
	A.I.type EZReader Theme Pack [85]	Keyboard design for Android smartphones with big keys, high contrast, helpful colors, and audio aid, specially developed for people with visual problems
Asthma	Control of Allergic Rhinitis and Asthma Test (CARAT): dissemination and applications in primary care [86]	The authors talks about an app called m.Carat [87] developed for Android and iOS, consisting of several modules in which asthma and allergic rhinitis (ARA) patients can read news about ARA, record daily events and medications, quantify the level of control of their ARA, and note tasks or reminders
	SIGN Asthma Patient Guide [88]	Guidance for asthmatic patients and relatives in order to know and take control over their condition. It has a section dedicated to patients and other dedicated to parents or carers of asthmatic children
Diabetes	The development of an innovative mobile phone App for Type 1 diabetes alcohol education [89]	The authors develop the app for iOS and Android Type 1 diabetes friend: alcohol guide [90,91], which tries to educate young people with type 1 diabetes about alcohol, meeting clinical guidelines
	OnTrack Diabetes [92]	App for managing diabetes by tracking several data, such as blood glucose and pulse, medication, exercise, and weight
OA	PAGAS Portable and accurate gait analysis system [93]	Paper about a system called PAGAS (Portable and Accurate Gait Analysis System), which includes an Android app in a smartphone connected via Bluetooth to a sensor positioned on the foot and whose purpose is monitoring the gait of patients with altered gait because of different health conditons
	Osteoarthritis of knee [94]	App with information and animated exercises specially designed for osteoarthritis of knee
Depression	CBT for depression: a pilot RCT comparing mobile phone vs computer [95]	The authors use in their study the application VirtualClinic - The Get Happy Program [96] for iOS, which is a cognitive therapy intervention for the management of depression through a comic book story in which users will learn how to manage their depression
	Positive Thinking [97]	App that contains many quotes for helping depressed people and even allows users to write and share their own thoughts

Table 4. Analysis of features (Part 1) of the selected apps.

Condition	Name	Rating	Class	Internet requirement	Clinical/Non-clinical	Data visualization
Anemia	SickleSAM (not commercial)	-	Tracking	No	Clinical	Graphs
	MD Series: Anemia – Free	4.9	Educational	No	Both	Text
Hearing loss	OtoID (not commercial)	-	Diagnosis	No	Clinical	Text, graphs
	Hearing Tests	3	Diagnosis	No	Nonclinical	Text
Migraine	iBMM (not commercial)	-	Educational, guidelines, monitoring	Some functions	Both	Video, graphs, text
	My Headache Log Pro	4.1	Monitoring	Only for sending mails	Both	Text, graphs
Low vision	VizWiz	4.5	Assistive	Yes	Nonclinical	Photos, text, audio
	EZReader Theme Pack	4.4	Assistive	No	Nonclinical	Text, audio
Asthma	m.Carat	-	Monitoring, assistive	Some functions	Nonclinical	Graphs, text, pictures
	SIGN Asthma Patient Guide	4.9	Informative, guidelines	Some functions	Nonclinical	Text, pictures
Diabetes mellitus	Type 1 diabetes friend: alcohol guide	-	Educational, informative	Some sections	Nonclinical	Text, photos
	OnTrack Diabetes	4.5	Monitoring	Only for sending mails	Both	Text, graphs
Osteoarthritis	PAGAS (not commercial)	-	Medical results	No	Both	Text, graphs
	Osteoarthritis of knee	5	Treatment	No	Nonclinical	Text, video
Depression	VirtualClinic – The Get Happy Program	-	Educational, guidelines	Unknown	Nonclinical	Pictures, comic, text
	Positive thinking	4.3	Kind of treatment	Some functions	Nonclinical	Text

Table 5. Analysis of features (Part 2) of the selected apps.

Name	Context awareness	Therapist intervention	Interaction with users	Frequency of use	Interface	Public
SickleSAM (not commercial)	User, location	Yes	No	Continuous	Simple	School children
MD Series: Anemia – Free	No	-	No	Occasional	Not intuitive	Anemia specialists
OtoID (not commercial)	Ambient noise	Yes	No	Regular	Basic	Ear specialists
Hearing Tests	No	No	No	Occasional	Basic	General
iBMM (not commercial)	No	Yes	No	Frequency of migraine attacks	Not intuitive	General
My Headache Log Pro	Preferences, location	Possible	No	Frequency of migraine attacks	Complex, several functions	General
VizWiz	Location	No	Yes, several ways	Frequent	Simple	General
EZReader Theme Pack	Language	No	No	Every time keyboard is used	Basic	General
m.Carat	User, preferences, language	No	No	Constant	Complex	General
SIGN Asthma Patient Guide	No	No	No	Occasional	Basic	General
Type 1 diabetes friend: alcohol guide	No	No	No	Occasional	Simple	Young people (aged 18-21)
OnTrack Diabetes	Preferences	Possible	No	Several times per day	Normal, several functions	General
PAGAS app (not commercial)	Sensor	Possible	No	Regular	Basic	General
Osteoarthritis of knee	No	No	No	Frequent	Simple	General
VirtualClinic – The Get Happy Program	Unknown	No	No	Regular	Simple	General
Positive thinking	Preferences	No	No	Regular	Basic	General

Figure 2. Snapshot of MD Series: Anemia–free.

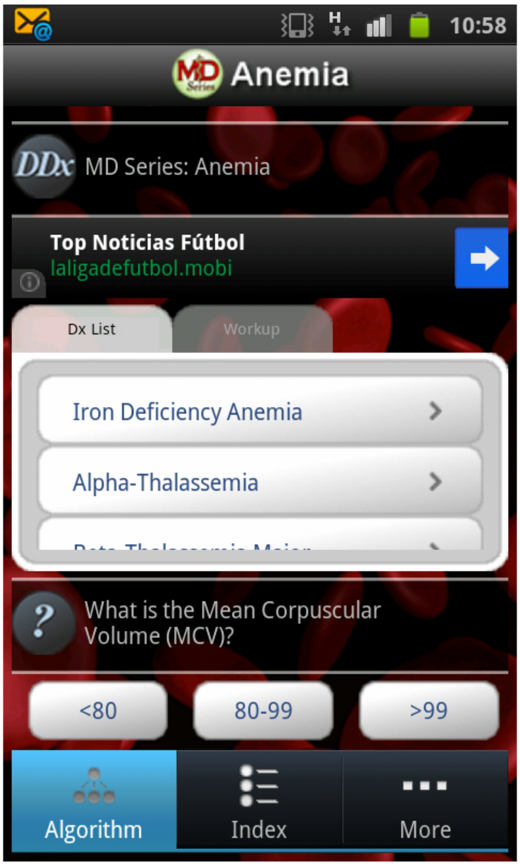


Figure 3. Snapshot of hearing tests.

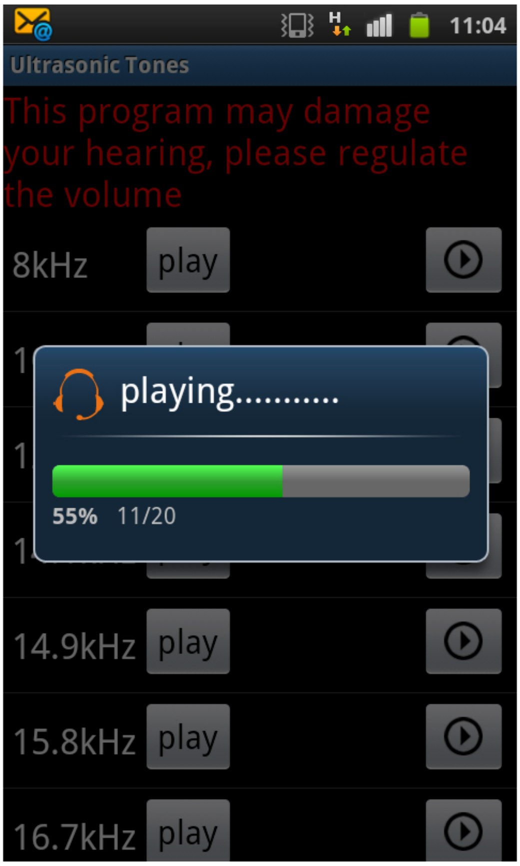


Figure 4. Snapshot of My Headache Log Pro.

Figure 5. Snapshot of AI type EZReader theme pack.

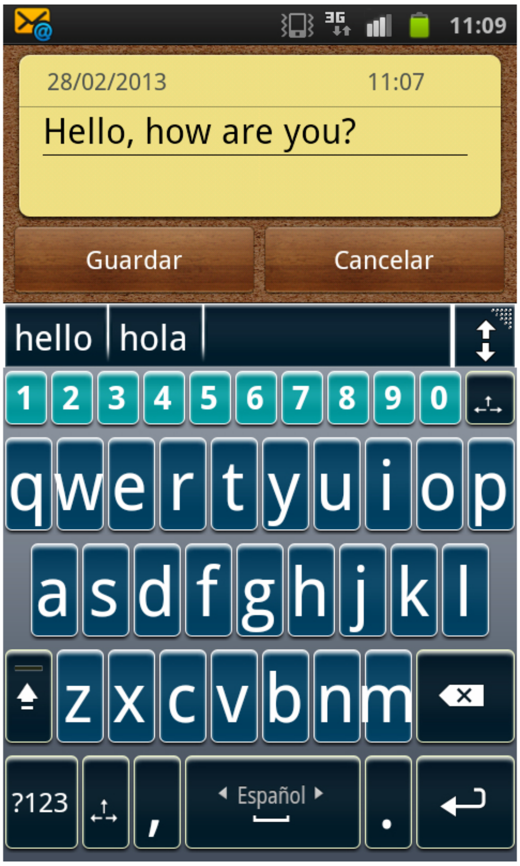


Figure 6. Snapshot of SIGN asthma patient guide.

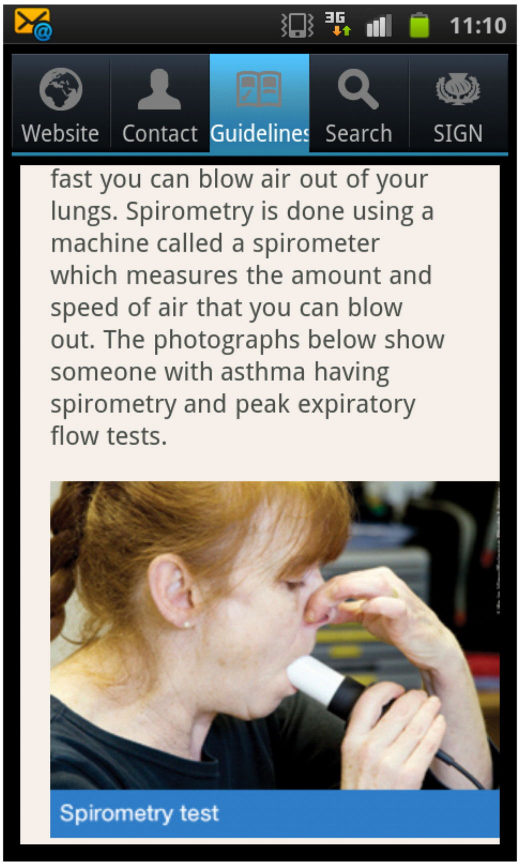


Figure 7. Snapshot of OnTrack Diabetes.

Figure 8. Snapshot of Osteoarthritis of knee.

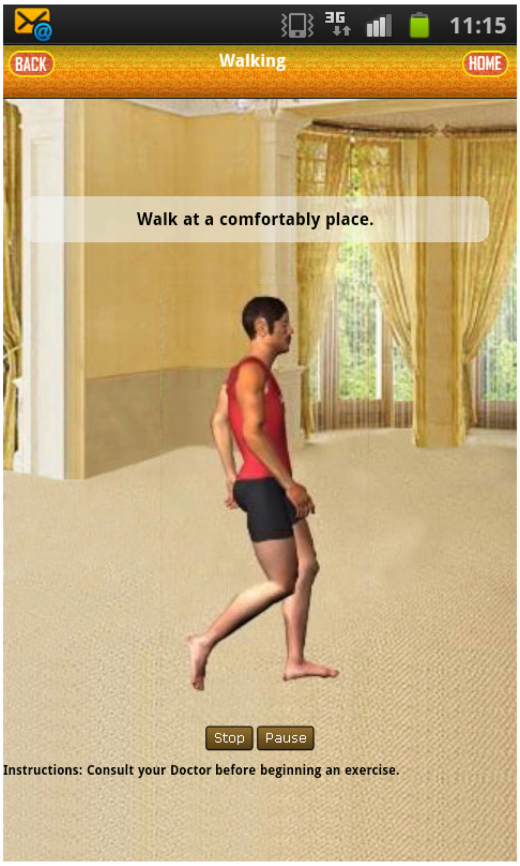
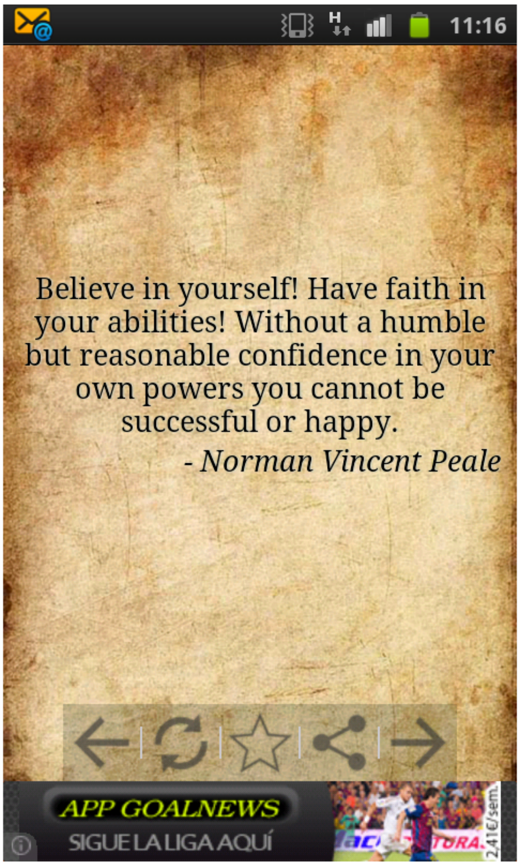


Figure 9. Snapshot of Positive thinking.



Discussion

The results of the literature and the commercial reviews show several interesting conclusions. First, the literature review indicates that there are few results compared to the commercial review. This means that the development of mHealth apps has a commercial and economic motivation more than a research motivation. Maybe it would be better to merge both, ie, first developing an app while investigating and then using it for commercial purposes.

Another important finding is the difference in the number of mobile applications for different conditions. There are conditions with more than 1000 apps, such as diabetes or depression while there are others with a range between 14 and 112 apps. The most prevalent condition (anemia) is surprisingly the second with less research and the first with less commercial apps, while two of the less prevalent (diabetes and depression) are the object of a huge number of applications and research. This may be because the majority of IDA cases are located in underdeveloped or developing countries [17,18] where smartphones or tablets are not as widely spread as in the developed countries, and therefore, it is not worthwhile developing apps for IDA. Meanwhile, diabetes or unipolar depression are common conditions associated with modern lifestyles typical of developed zones where there is a strong social conscience of these conditions. However, this is not borne out when comparing the numbers of those affected by diabetes or depression and by IDA in developed countries, because IDA is more extended in these zones than the others. Hence, the probable explanation for this lack of apps for IDA is that the social conscience of it is much less than that of the others and, therefore, it is underinvestigated. For this reason, in light of the numbers, it could be profitable and worthwhile creating apps for IDA.

Following the previous finding, the four most prevalent conditions have fewer apps and research than the remaining four, excluding OA. In addition, there is an important social factor for some of the most prevalent conditions, such as hearing loss or low vision. Therefore, it seems that there is a lack in the research on apps for these conditions and an opportunity for developers.

Contrasting the literature review with the commercial review, it is worth highlighting the cases of asthma and migraines. In the literature, asthma has more results than depression, but it has far fewer results in the commercial review. The opposite occurs with migraines, which move from the last position in number of literature results to the third position in the commercial review. Therefore, there is more work done on commercial apps for migraines than in research apps, as opposed to the situation for asthma.

Finally, comparing the number of apps available on each store, it is clear that application developers prefer Android and iOS for their projects, followed distantly by Windows Phone. Ovi Store and BlackBerry World suffer from a significant lack of apps, which means that developers are not interested in these markets. This is somewhat surprising in the case of BlackBerry since it is the third smartphone platform in market share [71]; hence, there may be an opportunity for developers to fill this empty space in BlackBerry's app store.

Determined criteria were followed in order to select the latest apps published in literature and the most popular and best valued by users' apps in commercial stores. The goal was to choose a sample of reference apps to analyze. These findings are given below.

The majority of apps are for monitoring, assistance, or informing about the condition. In general, apps for diabetes, migraines, and asthma are designed for monitoring the condition, and many have informative sections (or stand-alone informative apps). Apps for low vision are principally assistive, and the aim of most apps for depression is to raise the mood of the affected in several ways. But there are also informative and educational apps, which cover the other conditions, except for anemia, for almost every app is aimed for professional caregivers. For OA, there are an equal number of educational tools and apps with remedies or exercises for managing the pain, and for hearing loss the apps are divided between apps for hearing checks and informative apps.

Table 4 shows that for most apps, the Internet is not required or only required for some functions such as sending emails, which is useful for circumstances or situations where an Internet connection is not available. However, there are apps where an Internet connection is required, eg, for VizWiz. Typically the apps are not designed only for clinical purposes; proof of this is that only some apps developed for research are intended for clinical use. Others can have nonclinical and clinical use (always with the consent of the professional caregiver), but the majority have nonclinical purposes. In addition, there is a link between clinical apps and therapist intervention: if the app is clinical, the therapist intervention is needed. If the app is applicable for both clinical and nonclinical use, the therapist intervention is possible, but not obligatory. With respect to users' interaction, most of the apps do not have this functionality and work as stand-alone apps. Only those conditions that can be relieved in some way with the collaboration of other affected individuals or a determined community of users, such as depression or diabetes, have apps with modules used for these communications.

According to the results, the preferred method of data visualization is text, followed by graphs and pictures or photos. Whereas text visualization is used in almost every case, the use of graphs is common in monitoring or tracking applications in order to show data in a more comfortable and visual way. Something similar occurs with pictures and videos, which are normally used in apps with educational or informational purposes, while audio is a typical aid of low vision apps and is also used for hearing tests in hearing loss apps. Apps with only text visualization or with text and pictures have generally a basic or simple interface, whereas those with graphs or more than two visualization types have a more complex interface, not necessarily intuitive at first use. It is not shocking for apps with several types of data visualization to have a complex interface with several functions, but it is surprising that some of them have such unintuitive ones. Developers need to be careful when designing the interface and its use.

Generally there is no relation between the type of apps and the types of context awareness. Only location awareness can be linked to tracking and monitoring apps where it is important to state the place where an event occurs. For frequency of use, monitoring and assistive apps have a continuous or very frequent use, depending in some cases, such as migraine or asthma, on the frequency of the attacks. The same happens with apps designed to provide some kind of treatment. On the other hand, educational or informative apps are used more infrequently. It might be a good idea to merge monitoring and educational tools in the same app in order to improve frequency of use, number of users, and economic profit, but always with special attention to the interface design. Finally, the majority of the apps analyzed are aimed for the general public who are affected by each condition, which is logical because usually developers do not want to reduce their user circle.

For future work there are various paths to take. It is necessary to fill the lack of anemia apps by creating one aimed for patients, first educational and informative and then exploring other possible opportunities. Another field to populate is related to low vision and hearing loss apps because, as said before, there are few compared with other less prevalent conditions. Nevertheless, in this case it is important to carefully select the intended user because most people with severe hearing loss or low vision problems are over 60 years old in developed countries and do not usually use a smartphone [98]. Hence, designing an assistive app for a 16-50 year-old deaf/blind (or with a severe disability) target group that typically has smartphones can be very useful for the user and even profitable for the developers. In addition to this, the possibilities for creating assistive apps in these fields are enormous.

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Conflicts of Interest

None declared.

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Abbreviations

ARA: asthma and allergic rhinitis
CARAT: Control of Allergic Rhinitis and Asthma Test
CBT: cognitive behavioral therapy
GBD: global burden of disease
GOe: Global Observatory for eHealth
HSPA: High-Speed Packet Access
IDA: iron-deficiency anemia
IDC: International Data Corporation
OA: osteoarthritis
PAGAS: Portable and Accurate Gait Analysis System
PDA: personal digital assistant
RCT: randomized controlled trial
RFID: Radiofrequency Identification
RIM: Research In Motion Limited
SIGN: Scottish Intercollegiate Guidelines Network
SRO: sensitive range for ototoxicity
WBAN: Wireless Body Area Network
WHO: World Health Organization
WiMAX: Worldwide Interoperability for Microwave Access
WLAN: Wireless Local Area Network
WPAN: Wireless Personal Area Network
WSN: Wireless Sensor Networks

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Health Apps for the Most Prevalent Conditions

B. Martínez-Pérez, I. de la Torre-Díez, and M. López-Coronado

Department of Signal Theory and Communications, and Telematics Engineering,
University of Valladolid, Valladolid, Spain

Abstract—**In the last years, significant improvements in communications and technology have boosted the m-health to the point of being available thousands of health apps for smartphones and tablets. The main aim of this paper is to develop a study of the existing apps in the most important commercial stores for the 5 most prevalent health conditions issued by the last update of the *Global Burden of Disease* by the World Health Organization, understanding prevalence as the number of individuals who have the disease or condition at any moment. These conditions are iron-deficiency anemia, hearing loss, migraine, low vision and asthma. For this objective, it has been carried out a review of the apps for these conditions on the most important apps stores and an in-depth analysis of a sample of reference apps related to them. 356 relevant apps were found on the stores Google play, iTunes, BlackBerry World and Windows Phone Apps+Games in February 2013. From these apps, the most relevant of each condition by specific selection criteria were selected for being analyzed. Some interesting findings could be deduced from the results obtained. There is an alarming low number of apps for BlackBerry compared to the rest of systems. Despite anemia is the most prevalent condition, there are very few apps for it and no one aimed for patients. There are more apps for migraine and asthma than for the rest and they are divided into informative and monitoring apps whereas the majority of those for hearing loss and low vision are assistive.**

Keywords—**apps, m-health, prevalent health conditions, smartphones' stores, World Health Organization.**

I. INTRODUCTION

A. Background

The health is the most important matter in the life of an individual. If one is not healthy other issues lacks importance, hence humans have been always studying aspects of health and medicine. In the last decades, the irruption of the Internet, and the important advances in wireless communications have propitiated the creation and the expansion of m-health [1]. The more than 6 billion mobile phone subscriptions worldwide out of which 1.08 are smartphones [2-4] (not to mention the tablets) make these mobile devices an exceptional opportunity for providing health care everywhere and at every moment by using apps designed for health care [5].

But even with the last advances in these fields, there are still many diseases affecting people worldwide. According to the last Global Burden of Disease [6] by the World Health Organization (WHO), 58.8 million deaths occurred globally in 2004 and, out of every 10 deaths, only one was caused by injuries. In this year, there were also 18.6 million people severely disabled and 79.7 million moderately disabled. It has especial importance the prevalence of a disease or health condition, understood as the number of individuals who have the disease or condition at any moment.

The main aim of this paper is to study the commercial apps of the most important apps stores exclusively dedicated to the 5 most prevalent conditions by [6] and to carry out an analysis of features of a representative selection of the apps for each condition. The remainder of the paper is structured as follows. Next subsection is about the 5 most prevalent conditions. The following section describes the methodology used. After this, there are shown the results obtained from the review of the stores and the analysis of the mobile applications. Finally the discussions and conclusions are presented.

B. The Most Prevalent Conditions

The 5 most prevalent conditions by [6] are iron-deficiency anemia, hearing loss, migraine, low vision, and asthma. Figure 1 shows the prevalence in million individuals of each condition and below there is a brief description of these conditions.

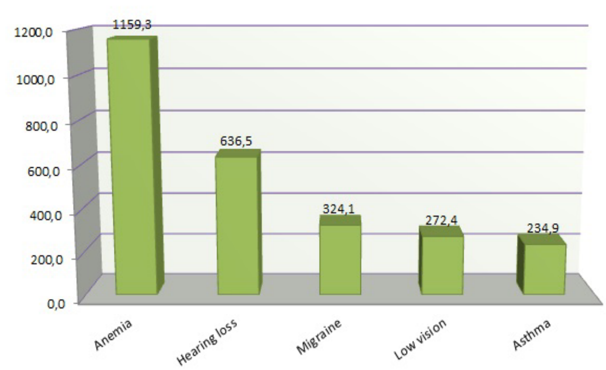

Fig. 1 Prevalence of the most prevalent conditions by the WHO

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Incorrectly, it is common to use the concepts anemia and iron-deficiency anemia (IDA) indistinctively, but they are not the same: anemia has its source in several causes together or isolated, but the most important contributor is iron deficiency [7]. IDA has also multifactorial sources, but all of them result in the fact that there is not enough absorption of iron by the person, no matter the cause. IDA's consequences are diminished exercise capacity, immune dysfunction, impaired thermoregulation and gastrointestinal disturbances, among others. [7-8].

Hearing loss or hearing impairment is defined by the WHO as *"the inability to hear as well as someone with normal hearing"*. This includes minor hearing loss to deafness [9]. There are various types of hearing loss and some of the most common causes are congenital, infectious diseases, excessive noise, ototoxic medications, head or ear injuries and presbyacusis. The effects of this condition have social and economic consequences, not only in individuals, but also in communities [10-11].

Although the pathophysiology of migraine is not totally known, it has its origins in an *"activation of a mechanism deep in the brain which causes release of pain - producing inflammatory substances around the nerves and blood vessels of the head"* [12]. It is not known why these attacks occur periodically and what process finishes spontaneously these attacks. Some common characteristics of migraine are strong headache, nausea and intolerance for some light and noise conditions. These episodes entail important social and economic negative aspects [12-14].

Understood as visual acuity less than 6/18 and equal or better than 3/60 due to refractive errors, cataracts, glaucoma or macular degeneration, low vision cause difficulties in almost every aspect of the life of the person: things we see normal such as dressing, walking, communicating and interacting can be very hard for people with low vision, not to mention blind [15-17].

The WHO defines asthma as *"a chronic disease characterized by recurrent attacks of breathlessness and wheezing, which vary in severity and frequency from person to person"* [18]. The causes are not fully understood, but it is known that the genes and the environment are very important in its development. 75-80% of all asthmatic cases are caused by a response to an allergy and the triggers of asthma attacks are inhaled particles [18-20].

II. METHODS

The research of the apps were carried out in the most important application stores [21-22] which are, in descending order of market share of operative systems for smartphones, Google play of Google Android [23], iTunes of Apple [24], BlackBerry World of BlackBerry (previously known as RIM or Research In Motion Limited) [25] and Windows Phone Apps+Games Store of Microsoft [26].

The name of the condition was searched but if the search returned few or no results, it was tried other name, as happened with iron-deficiency anemia, searching just "anemia". The criteria of selection of apps were the following: applications had to be in English or in the language of the country where the search was executed (Spanish), focused on the sought condition, not included in the categories of entertainment, games or music, designed for human care (not veterinarian) and not being magazines or journals.

During the search we faced two issues. The first was that, on iTunes, apps for iPod and iPhone were separated from the ones for iPad, therefore only apps for the first one were searched. The second difficult was a problem with the web page of Google Play [23]. In some searches, the site said that a certain number of results have been found but while exploring the pages of the results the last pages were blank, being the number returned different from the number of apps showed. In these cases it was considered the last one.

For the in-depth analysis an application was chosen for each condition. It was decided to select apps for Android as it is the most extended software in smartphones [21-22]. For each condition, the first relevant free app with a rating by users of 3 or more stars which Google play showed when searching by the condition and sorted by popularity was selected. Furthermore, another requisite was that the app had to be developed for patients, not for health care professionals. So, summing up, the app chosen for analysis was the most popular free one associated to the condition with an evaluation over the mean and designed for patients. Nevertheless, all the results with a rating of 3 stars or more in the case of anemia were created for caregivers, so just in this case the app chosen did not fulfill the last requisite of being aimed for patients. The apps were tested on a Samsung Galaxy S SCL GT-I9003.

III. RESULTS

A. Review of Commercial Apps

Table 1 includes the results of the review, showing the number of significant apps out of the total number of applications found in each store for each condition. The last row shows the addition of all the apps found for store and the last column contains the addition of all the apps found for condition. It is important to state that the last does not mean the total number of apps for a specific condition because there are apps designed for several systems. For example, one app found on iTunes can also be found on Google play.

Table 1 Results of the apps review

	Google play	iTunes	BlackBerry	Windows	**Total**
Anemia	7/74	7/21	0/0	0/0	**14**
Hearing loss	17/42	32/37	0/0	3/5	**52**
Migraine	57/201	46/102	5/6	4/8	**112**
Low vision	33/43	30/46	0/0	4/8	**64**
Asthma	44/226	57/124	6/7	4/14	**112**
Total	**158**	**172**	**11**	**15**	

In light of the results, it is obvious that iTunes and Google play are the stores with more apps, followed distantly by Windows Phone Apps+Games and being BlackBerry World the last. Comparing the conditions by their numbers of apps, migraine and asthma are the ones with more apps, followed by low vision and hearing loss. Finally, anemia is the last.

B. Analysis of Representative Apps

The commercial apps that fulfill the requisites explained in the Methods section and, therefore, selected for the in-depth analysis were: MD Series: Anemia – Free [27]; Hearing Tests [28]; My Headache Log Pro [29]; A.I.type EZReader Theme Pack [30] and SIGN Asthma Patient Guide [31].

MD Series: Anemia – Free is an app designed for caregivers which provides several tools for the diagnosis and treatment of different types of anemia in adult patients. These tools have an educational purpose [27]. Hearing Tests is basically a hearing examination which uses sounds of diverse frequencies to provide to the user an auto-diagnosis for his hearing. [28]. My Headache Log Pro is a diary where the user can note the headache attacks suffered, with its triggers, symptoms and medications used, permitting also to email these records to the doctor [29]. A.I.type EZReader Theme Pack is a keyboard design for Android smartphones with bigger keys than the ones of normal keyboards, higher contrast, helpful colors and even audio aid which reproduces what the user have written, and it is specially developed for people with visual problems, [30]. SIGN Asthma Patient Guide is a guide for both asthmatic patients and relatives in order to help families to know and take control over this condition. For this purpose, it has two sections, one dedicated to patients and other dedicated to carers of asthmatic children [31]. Figure 2 shows some snapshots of the apps analyzed.

Fig. 2 Snapshots of (a) MD Series: Anemia – Free, (b) Hearing Tests, (c) My Headache Log Pro, (d) A.I.type EZReader Theme Pack and SIGN Asthma Patient Guide.

In Table 2 there are shown the results of the analysis of some characteristics of the selected applications.

Table 2 Analysis of features of the representative apps

	MD Series: Anemia	Hearing Tests	My Headache Log Pro	A.I.type EZ-Reader	SIGN Asthma
Rating	4.9	3	4.1	4.4	4.9
Class	Educational	Diagnosis	Monitoring	Assistive	Informative
Internet requirement	No	No	Only for mails	No	Some functions
Clinical/Non-clinical	Both	Non-clinical	Both	Non-clinical	Non-clinical
Data visualization	Text	Text	Text, graphs	Text, audio	Text, pictures
Context awareness	No	No	Preferences, location	Language	No
Therapist intervention	-	No	Possible	No	No
Frequency of use	Occasional	Occasional	Frequency of attacks	Continuous	Occasional
Interface	Complex	Basic	Complex	Basic	Basic
Public	Specialists	General	General	General	General

IV. DISCUSSION AND CONCLUSIONS

Several interesting findings can be extracted from the results. The most striking is that the most prevalent condition (IDA) is the one with less apps while the less prevalent (asthma) is the one with the highest number of apps (with migraine). This can be explained by two facts. The first is that the majority of the cases of IDA are located in underdeveloped or developing countries [6, 32] where smartphones or tablets are not spread so it is not worthwhile developing apps for IDA. However, this fact alone does not explain the situation because IDA is even more extended than asthma in developed countries and it is necessary a second fact: there is not a social conscience of IDA as strong as the one formed for asthma and, therefore, it is under-investigated. For these reasons and in light of the numbers, it can be profitable to create apps for IDA or anemia in general, filling this gap in the market.

Excluding the case of IDA, the conditions with more apps are migraine and asthma whereas hearing loss and low vision have less apps, despite hearing loss is more prevalent than migraine and asthma, and low vision is more prevalent than asthma. These results can be explained by the sort of treatment these conditions have. On one hand, hearing loss and low vision are conditions that affect human senses and can be easily treated in most cases with hearing aid and glasses respectively, or even with surgical operations. On the other hand, migraine and asthma have not cure and, in fact, the origin of these conditions is unknown [12, 14, 18-19], therefore the treatment consists of monitoring the attacks of the conditions and the use of some medication for a better management and control [13, 20]. Developers may have seen this point and used it for developing apps for monitoring these conditions, whereas this type of apps cannot be used for hearing loss or low vision, explaining the difference in the numbers of apps for these conditions.

Comparing the number of apps available in each store, Android and iOS are the systems with more apps, followed distantly by Windows Phone, whereas BlackBerry is the one with less apps. This classification corresponds with the market share except the case of BlackBerry, which is the third smartphone platform in market share over Windows Phone [21-22]. It seems that developers are not spending their time in this platform and this can be both cause and consequence of the loss of market share of BlackBerry.

From the review and the analysis of the apps it can be said that, in general, apps for anemia are aimed for aiding in its diagnosis whereas apps for hearing loss are divided in two types: hearing checks and informative apps. As it was mentioned previously, apps for migraine and asthma are designed for monitoring and there are also informative apps. Low vision has principally assistive apps.

Usually, Internet is not required or just needed for some functions such as sending emails, which is an advantage in situations where the Internet connection is not available. Normally, the apps are not designed for clinical purposes, at least not only for them. In addition to this, if an app is for non-clinical use then there is no therapist intervention but if it can have both clinical and non-clinical use, the therapist intervention can be possible.

The preferred method of data visualization is text, which is used in every case and can be combined in some occasions with graphs, common in monitoring apps to show data in a more comfortable way, and pictures, normally used in apps with informational or educational aims. Audio is usually used in low vision apps and in hearing loss apps for hearing tests. The interface is connected to data visualization in the way that apps with only text or with text and pictures have a simple interface whereas apps with graphs have a complex one. The exception occurs with the app for anemia, which has a complex use, even not instinctive at first sight.

As it can be seen, there is no relation between the type of apps and the context awareness. Focusing on frequency of use, monitoring and assistive apps have a continuous or very frequent use and in some cases, such as migraine, it depends on the frequency of the attacks. On the other hand, apps for diagnosis and educational or informative apps are used more occasionally. Finally, all the analyzed apps are aimed for general public, excluding the one for anemia which is designed for specialists. This is normal because developers want the most number of users for its applications, not focusing only on a specific type of users.

For future work, various lines can be followed. It was seen that there are no apps for anemia aimed for patients so it can be a good idea to design and create one, which can be educational and informative and, this way, fill this gap in the market. Another way of action can be developing applications for low vision or hearing loss, since there are few apps compared with other health conditions such as asthma and migraine.

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Author: Borja Martínez Pérez
Institute: University of Valladolid
Street: Paseo de Belén 15
City: Valladolid
Country: Spain
Email: borja.martinez@uva.es

Review

Comparison of Mobile Apps for the Leading Causes of Death Among Different Income Zones: A Review on Literature and Apps Stores

Borja Martínez-Pérez*, MSc; Isabel de la Torre-Díez*, PhD; Miguel López-Coronado*, PhD; Beatriz Sainz-De-Abajo*, PhD

University of Valladolid, Department of Signal Theory and Communications, and Telematics Engineering, University of Valladolid, Valladolid, Spain

*all authors contributed equally

Corresponding Author:
Borja Martínez-Pérez, MSc
University of Valladolid
Department of Signal Theory and Communications, and Telematics Engineering
University of Valladolid
Paseo de Belén, 15
Valladolid, 47011
Spain
Phone: 34 983423000 ext 3703
Fax: 34 983423667
Email: borja.martinez@uva.es

Abstract

Background: The advances achieved in technology, medicine, and communications in the past decades have created an excellent scenario for the improvement and expansion of eHeath and mHealth in particular. Mobile phones, smartphones, and tablets are exceptional means for the application of mobile health, especially for those diseases and health conditions that are the deadliest worldwide.

Objective: The main aim of this paper was to compare the amount of research and the number of mobile apps dedicated to the diseases and conditions that are the leading causes of death according to the World Health Organization grouped by different income regions. These diseases and conditions were ischemic heart disease; stroke and other cerebrovascular diseases; lower respiratory infections; chronic obstructive pulmonary disease; diarrheal diseases; HIV/AIDS; trachea, bronchus, and lung cancers; malaria; and Alzheimer disease and other dementias.

Methods: Two reviews were conducted. In the first, the systems IEEE Xplore, Scopus, Web of Knowledge, and PubMed were used to perform a literature review of applications related to the mentioned diseases. The second was developed in the currently most important mobile phone apps stores: Google play, iTunes, BlackBerry World, and Windows Phone Apps+Games.

Results: Search queries up to June 2013 located 371 papers and 557 apps related to the leading causes of death, and the following findings were obtained. Alzheimer disease and other dementias are included in the diseases with more apps, although it is not among the top 10 causes of death worldwide, whereas lower respiratory infections, the third leading cause of death, is one of the less researched and with fewer apps. Two diseases that are the first and second of low-income countries (lower respiratory infections and diarrheal diseases) have very little research and few commercial applications. HIV/AIDS, in the top 6 of low-income and middle-income zones, is one of the diseases with more research and applications, although it is not in the top 10 in high-income countries. Trachea, bronchus, and lung cancers are the third cause of death in high-income countries but are one of the least researched diseases with regard to apps.

Conclusions: Concerning mobile apps, there is more work done in the commercial field than in the research field, although the distribution among the diseases is similar in both fields. In general, apps for common diseases of low- and middle-income countries are not as abundant as those for typical diseases of developed countries. Nevertheless, there are some exceptions such as HIV/AIDS, due to its important social conscience; and trachea, bronchus and lung cancers, which was totally unexpected.

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KEYWORDS

apps; different income zones; leading causes of death; mobile apps; World Health Organization (WHO)

Introduction

The advances in science and medicine in developed countries have caused an elderly population and long-term survival of individuals who suffer chronic diseases due to modern treatments and cures. This has increased the quality of life expectation of health care consumers [1]. For satisfying this expectation, there have been important improvements in health care delivery supported by the use of the Internet, also known as eHealth, defined by the International Telecommunication Union as the paradigm that encompasses all of the information and communication technologies necessary to make the health system work [2,3]. This paradigm has evolved significantly to the point of creating mobile health (mHealth) as a branch of eHealth.

There are many definitions of mHealth. For some authors it is an area of eHealth that provides health services and information via mobile technologies such as mobile phones and PDAs [4,5]; for others, the term is defined as "emerging mobile communications and network technologies for healthcare systems" [6]. What is clear is that mobile devices are used for providing health care. More important than the definitions are the impressive development and dissemination this field has been achieving, to the point that Atienza et al (2011) have suggested that mobile health may be the "killer app" for cyberinfraestructure for health in the current century [7]. The reality is that important advances in technology and communications have been achieved in the past few years and mHealth has taken advantage of them [8-12]. mHealth is supported by many mobile telecommunications technologies, such as 3G (third generation) or 4G (fourth generation) technologies, for example [13-18].

The potential for mHealth applications is rather well-documented [19-21]; for example, move away from face-to-face visits at the doctor's office, access to a wide array of educational resources including information on disease-specific topics and general self-management tools, view your own electronic medical record, access information relative to medications, and continuous surveillance of vital or physiological signs.

In addition to this, advances in technology for smartphones and tablets have caused their incredible growth, especially in high-income countries. There were 6 billion mobile subscriptions in 2011 and more than 1.7 billion mobile phones sold in 2012, 712.6 million of which were smartphones. With these numbers, it is obvious that these devices must be used in the field of mHealth to assist every person with one of these gadgets. Indeed, mHealth is already using them as shown by the great number of health applications currently available [22-25].

These devices can be especially useful for the prevention and management of those diseases that cause high rates of mortality. The World Health Organization (WHO) estimated a total of 56.8 million deaths in 2008 and, excluding 5.1 million that were caused by injuries, the remainder were produced by diseases and health conditions [26]. Some of the leading causes of death are presented in Figure 1, which shows the percentage of deaths caused by these diseases and distributed according to different income zones [27].

The 6 leading causes of death for each zone and worldwide in 2008 are shown. When these diseases have 0% deaths represented in determined zones of Figure 1, it means that the diseases are not among the top 10 in this zone, but not that there are not deaths caused by those illnesses. Some data are presented below.

Considering randomly 1000 individuals dead in 2008, statistically 159 would have come from high-income countries, 677 from middle-income countries, and 163 from low-income countries [28]. Cardiovascular diseases (CVDs) are the deadliest diseases—17.3 million people died from CVDs in 2008, representing 30% of all global deaths [29]. Among these diseases, ischemic heart disease (IHD) is the leading cause of death globally with an estimated 7.3 million deaths [30-34]. Stroke produces not only death, but also disabilities and high probabilities of death in the future. Its burden is projected to rise from approximately 38 million DALYs (disability-adjusted life years) worldwide in 1990 to 61 million DALYs in 2020 [35-38].

Lower respiratory infections (LRI) are the leading causes of child mortality in the world, producing 1/5 of mortality in children under 5 years. The respiratory syncytial virus (RSV) is the single most important cause of severe respiratory illnesses in children and can provoke pneumonia, which causes 90% of these deaths due to the virus [39-43]. Sixty-five million people had chronic obstructive pulmonary disease (COPD) and more than 3 million died in 2005 [44-48]. Diarrheal disease is a major problem in developing countries and the second leading cause of mortality in children under 5 years of age, killing 1.5 million children every year [49-52].

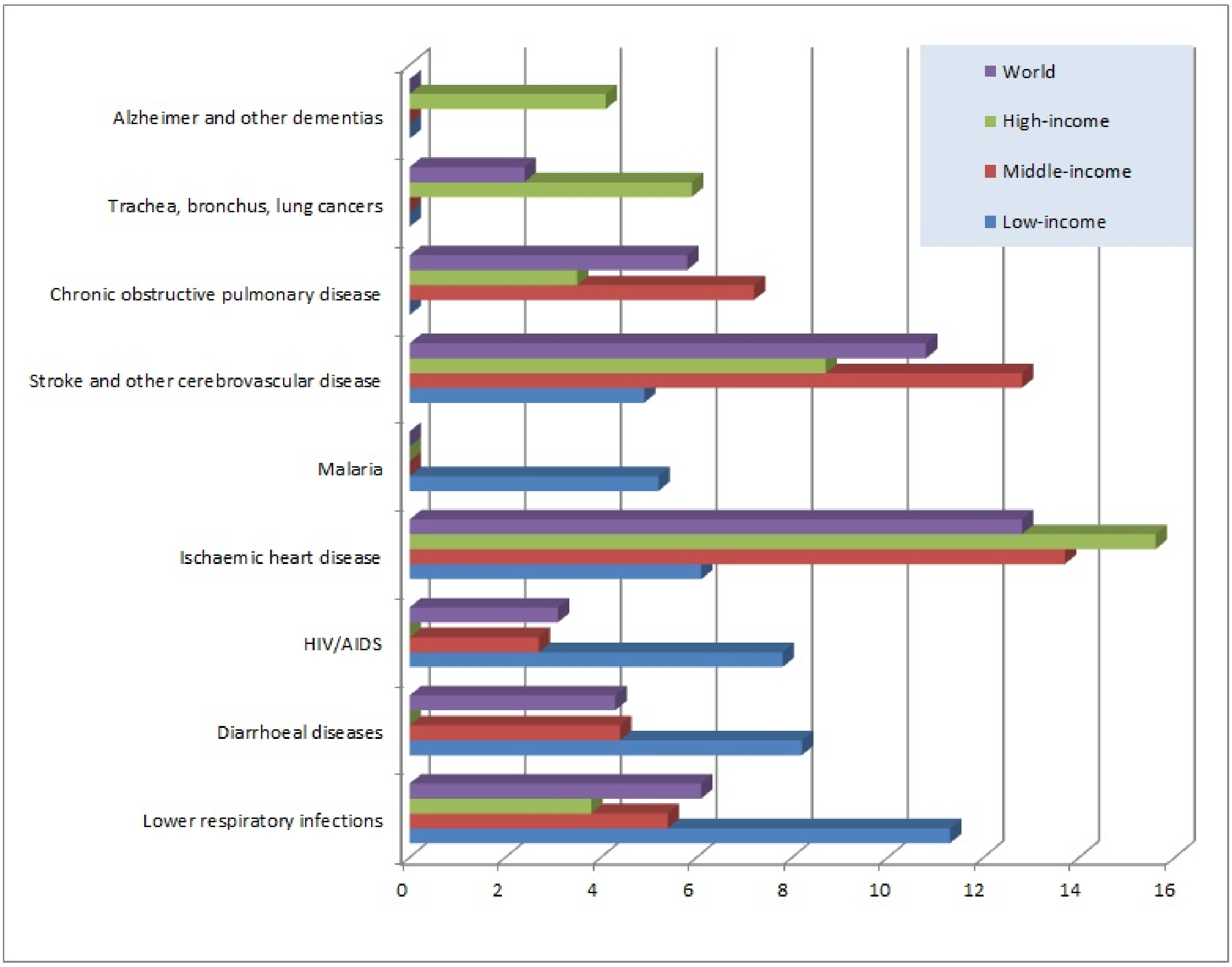
Human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS) is a major global public health issue. In 2011, there were 34 million people living with HIV and 1.7 million of whom died because of it. The political commitment, social mobilization, and HIV/AIDS funding done by almost every country in the past years have contributed to the total of 95 million people tested in 2010 and more than 8 million receiving antiretroviral therapy [53-57]. According to the WHO, there were 219 million cases of malaria and 660,000 deaths in 2010 [58-60]. However, other studies have worse numbers: Murray et al (2012) estimated 1.24 million deaths globally in 2010 [61].

Cancer caused 7.6 million deaths worldwide in 2008, with the majority caused by lung cancer (1.37 million deaths). Tobacco is the most important risk factor for developing cancer (not only lung cancer), causing 22% of cancer deaths and 71% of lung cancer deaths [62-65]. There are 35.6 million individuals suffering from dementia and 477,000 annual deaths worldwide.

Among the different dementias, Alzheimer disease is the most common with a contribution of 60%-70% of the cases and a median life expectancy of 7.1 years [66-70].

The main aim of this paper is to continue the research begun by the authors about mobile apps for the most prevalent health conditions [71], focusing on the diseases and conditions that are leading causes of death by the WHO grouped according to different income regions [27]. For this purpose, two reviews have been done. The first was a literature review carried out by searching published articles in several systems, and the second was a review of commercial apps done in the most important mobile phone apps stores considering the market share of the operative systems used for smartphones. The main objective is to find out which diseases are more researched and which have more apps, comparing these findings with their weight in mortality, not only globally but also distributed according to different income regions. This study is only limited to a general search of applications, without studying or analyzing them due to the significant extension of that work, which is enough for additional research.

Figure 1. Percentage of deaths caused by the leading causes of death grouped by zones.



Methods

Overview

In April 2013, two reviews were developed: a literature review and research in commercial applications stores. The procedures used for each review are explained below.

Literature Review

For the literature review, a search of published papers was developed in the following databases and systems: IEEE Xplore, Scopus, Web of Knowledge, and PubMed. When searching for a specific disease, a combination of search words was used. If the number of results obtained was too low, another combination of words was used until a more significant number of results was obtained. These terms were used on all the systems mentioned. The process was repeated with each disease studied. The search strings were used only for metadata and the article search was limited to the past 10 years, from 2003.

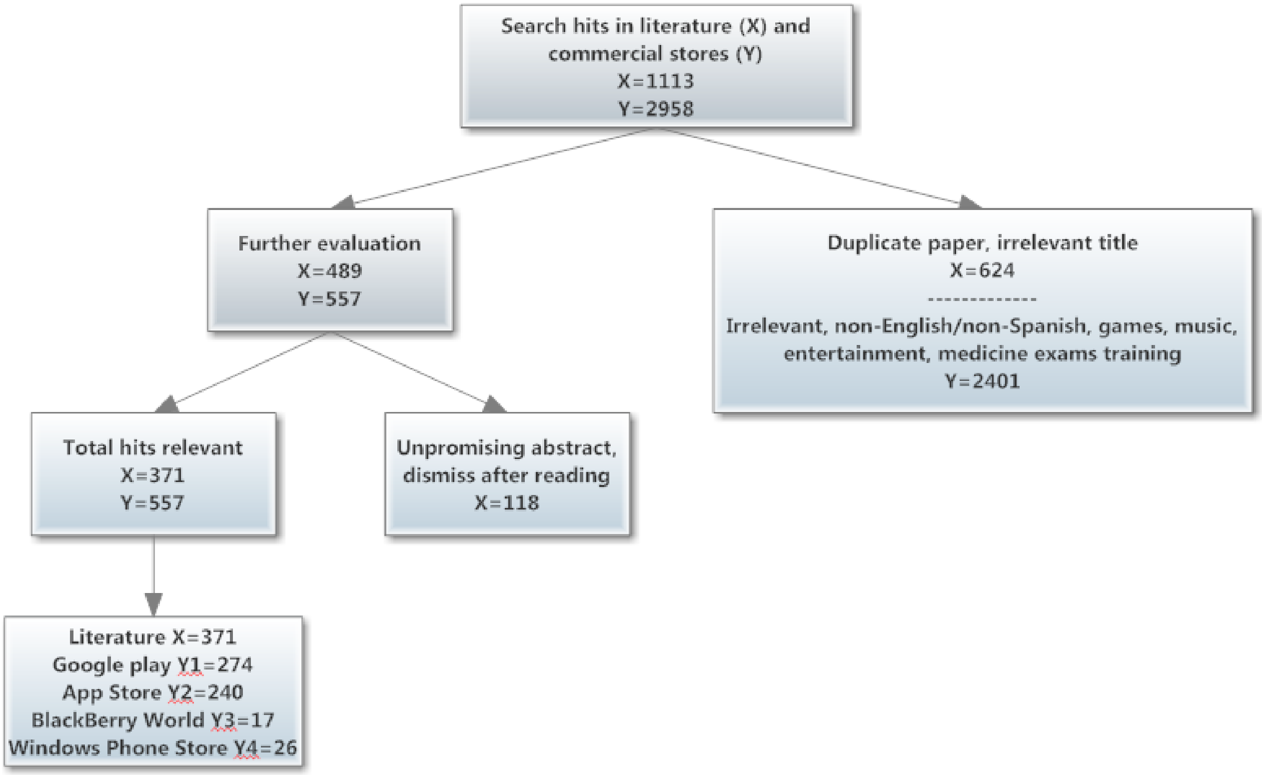
Table 1. Terms used in the literature search strings of each disease.

Disease	Term1	Term2
LRI	lower respiratory infections	application
	respiratory infections	application
	respiratory diseases	application/app
Diarrheal diseases	diarrhoeal diseases	application
	diarrheal diseases	application
	diarrhea	application/app
	diarrhoea	application/app
HIV/AIDS	HIV/AIDS	application/app
	HIV	
IHD	ischaemic heart disease	application/app
	ischemic heart disease	application
	heart disease	application/app
Malaria	malaria	application/app
Stroke and other cerebrovascular diseases	stroke	application/app
	cerebrovascular disease	
COPD	chronic obstructive pulmonary disease	application/app
	copd	
Trachea, bronchus, lung cancers	trachea cancer	application/app
	bronchus cancer	
	lung cancer	
	respiratory system cancer	
Alzheimer and other dementias	Alzheimer	application/app
	dementia	

Figure 2 shows a flowchart with the steps followed in both literature and commercial reviews. All the systems returned 1113 results, with 624 repeated or with an irrelevant title for this study. Of the remaining 489 papers, 118 were dismissed after reading their abstract or the whole paper when necessary. Finally, a total of 371 papers (33.3%) were selected as relevant. For considering a paper relevant, it had to fulfil some criteria: it must be focused on applications using mobile phones or devices, it must be written in English, and it has to be about a mobile app or apps designed for the sought condition. This means that papers centered on applications for several and different diseases were dismissed even if one of the illnesses treated was the one sought.

For the search strings, in some cases Britain and US terms for the same word were used to ensure that every relevant document was revealed. The combinations of words used were the following: Term1 AND mobile AND Term2, Term1 AND m-health; Term1 AND “mobile phone”; Term1 AND smartphone; where Term2 was app or/and application and for Term1 it was used the terms used for each disease that is shown in Table 1.

Figure 2. Flow chart of the steps followed in the reviews.



Commercial Apps Review

The second review was carried out in the most important applications stores of the smartphones industry considering the market share of the operative systems for smartphones [23-25,72]. In descending order of this market share, the stores are Google play of Google Android [73], iTunes of Apple [74], BlackBerry World of BlackBerry [75], and Windows Phone Apps+Games Store of Microsoft [76].

The process is similar to the one followed in the literature review. Table 2 shows the different terms used in the search of the applications related to each disease and the flowchart of Figure 2 shows the steps followed in the commercial review. A total of 2958 apps were initially found although, after checking whether the apps were relevant to the study and whether some conditions were fulfilled, only 557 (18.8%) met these requirements. The requisites to include an app in the study were applications not in English or with the description in a different language from English or the one of the country where the search was done (Spanish) were dismissed, the same as those included in the categories of games, music, or entertainment. Applications that use flashcards for helping medical students in their exams and applications for conferences were also dismissed.

Table 2. Strings used in the search of commercial apps for each disease.

Disease	Search String
LRI	respiratory infections
Diarrheal diseases	diarrheal disease
HIV/AIDS	HIV
IHD	“heart disease”
Malaria	malaria
Stroke and other cerebrovascular diseases	stroke; “cerebrovascular disease”
COPD	”chronic obstructive pulmonary disease”; copd
Trachea, bronchus, lung cancer	“trachea cancer”; “bronchus cancer”; “lung cancer”
Alzheimer and other dementias	alzheimer; dementia

Results

Mobile Apps in Literature

The results of relevant papers for each condition and each system are presented in Table 3. The last column shows the total number of different papers found on all the systems. The results of the search of the respiratory system cancers can be broken down into nine results for lung cancer and no results for the rest of the search strings (trachea cancer, bronchus cancer, and respiratory system cancer).

In light of the results, heart diseases are the most researched ones. It is followed by HIV/AIDS, Alzheimer and other dementias, and stroke and other cerebrovascular diseases. LRI and COPD hold the fifth and sixth places, respectively, in descending order of research done and the last places are for malaria, trachea, bronchus, lung cancers, and diarrheal diseases with very little investigation; only 28 articles among them.

The majority of papers found were relative to the design, development, or implementation of mobile systems, whole systems [77], complement systems to a mobile phone [78], or part of the system [79]. There are also evaluations and validations of these mobile systems [80]. Other types with a great number of papers found are interventions using mobile systems [81], apps [82], or mobile phones [83] and the studies and evaluations of these interventions [84]. Another type of paper found, but less frequent, are those dedicated to applications for smartphones, with add-on complements [85] or without them [86] and reviews of the existing apps for a specific objective [87].

Table 3. Results of the literature review.

Disease	IEEE	Scopus	Wok	PubMed	Total
LRI	9	21	9	3	24
Diarrhoeal diseases	0	3	1	0	3
HIV/AIDS	4	77	38	42	86
Heart diseases (IHD)	41	81	47	32	121
Malaria	1	15	9	8	16
Stroke and other cerebrovascular diseases	7	30	13	9	36
COPD	5	20	10	7	23
Trachea, bronchus, lung cancers	2	7	4	3	9
Alzheimer and other dementias	16	49	20	7	53

Mobile Apps in Stores

The findings of the commercial apps review are revealed in Table 4. Each cell shows the number of relevant apps out of the total number of results found in each commercial store. The last row contains the addition of the applications found for all the diseases at each store and the last column presents the addition of the applications found at all the stores for each sought disease. Nevertheless, this number does not represent the total number of different apps in all the stores, because there are apps developed by the same creator for different operative systems, being the same (or similar) app for different smartphones software. For example, the application AIDSinfo HIV/AIDS Glossary, created by the National Library of Medicine at National Institutes of Health (NIH) [88], is available on iTunes [89] and on Google play [90].

There are some diseases issued by the WHO that are actually a group, so in Table 4 these groups are divided into its illnesses. This way, the groups stroke and other cerebrovascular diseases and Alzheimer and other dementias are divided each one into two rows, one for stroke and cerebrovascular diseases and another for Alzheimer and dementia, respectively. The same occurs with the group trachea, bronchus, and lung cancers, split into three rows corresponding to the three types of cancer.

Focusing on the number of applications for each disease, the ones with more apps are Alzheimer and other dementias with 128, followed closely by HIV/AIDS. The third position is for heart diseases with 111 applications and the fourth is for stroke and other cerebrovascular diseases despite the fact that there are no results for cerebrovascular diseases. After a gap of more than 40 apps, COPD holds the fifth position and trachea, bronchus, and lung cancers the sixth, although there are no apps for the two first mentioned cancers, only for lung cancer. The seventh and eighth positions are malaria and diarrheal diseases, and the last is LRI with only 6 apps.

Table 4. Results of the commercial apps review.

Disease	Google play	iTunes	BlackBerry World	Windows Phone Store	Total
LRI	5/57	1/17	0/0	0/0	6
Diarrheal diseases	12/88	8/12	0/0	0/5	20
HIV/AIDS	54/238	56/121	7/8	7/19	124
Heart diseases (IHD)	60/249	44/79	3/4	4/21	111
Malaria	12/51	7/25	1/2	2/8	22
Stroke	27/480	45/530	4/46	3/105	79
Cerebrovascular diseases	0/0	0/2	0/0	0/0	0
COPD	20/50	17/37	0/0	1/3	38
Trachea cancer	0/0	0/1	0/0	0/0	0
Bronchus cancer	0/1	0/0	0/0	0/0	0
Lung cancer	14/88	14/54	1/3	0/2	29
Alzheimer	38/175	25/96	1/2	6/14	70
Dementia	32/185	23/70	0/0	3/10	58
Total apps per store	274	240	17	26	

The main types of apps for LRI are guides and calculators for health care professionals, although there are also some informative apps for patients. In the case of diarrheal diseases, the most common apps are natural and personal remedies as well as some guides. Referring to HIV/AIDS, there are many guides for health care professionals, patients and public in general, centering, in this case, on educational aspects. There are also a significant number of apps with news regarding HIV/AIDS. The great majority of apps for heart disease are heart rate monitors for patients and algorithms and calculators for specialists [91]. The principal focus of malaria apps is to use the smartphone as a mosquito repellant, followed by informative apps about it. The most usual apps for stroke and other cerebrovascular diseases are stroke detectors and stroke scale calculators. There are also some informative apps.

Referring to COPD, the majority of apps are informative and guides for health care professionals, followed by some COPD trackers and apps for learning to use inhalers, both destined for patients. Focusing on lung cancer (there are no specific apps for the rest of cancers studied), most apps are destined for cancer stage determination and help in its diagnosis for professionals. For patients, informative apps are common. Finally, typical apps for Alzheimer and other dementias are games useful for their prevention, supportive apps for patients and relatives, as well as trackers and apps for auto-checking the status of a dementia.

Figure 3-5 show three graphs, which present the percentage of the number of apps found in the applications stores for each of the top 6 causes of death for each region, excluding the rest of the total (100%).

The diseases with a higher percentage of apps in low-income and middle-income countries are heart diseases (IHD) and HIV/AIDS, whereas in high-income countries these diseases are Alzheimer and other dementias, and heart diseases (IHD). LRI is the disease with the least percentage of apps in all the zones, followed by diarrheal diseases in low- and middle-income countries and trachea, bronchus, and lung cancers in high-income countries.

Figure 3. Percentage of apps (%) related to the top 6 causes of death of the low-income zone.

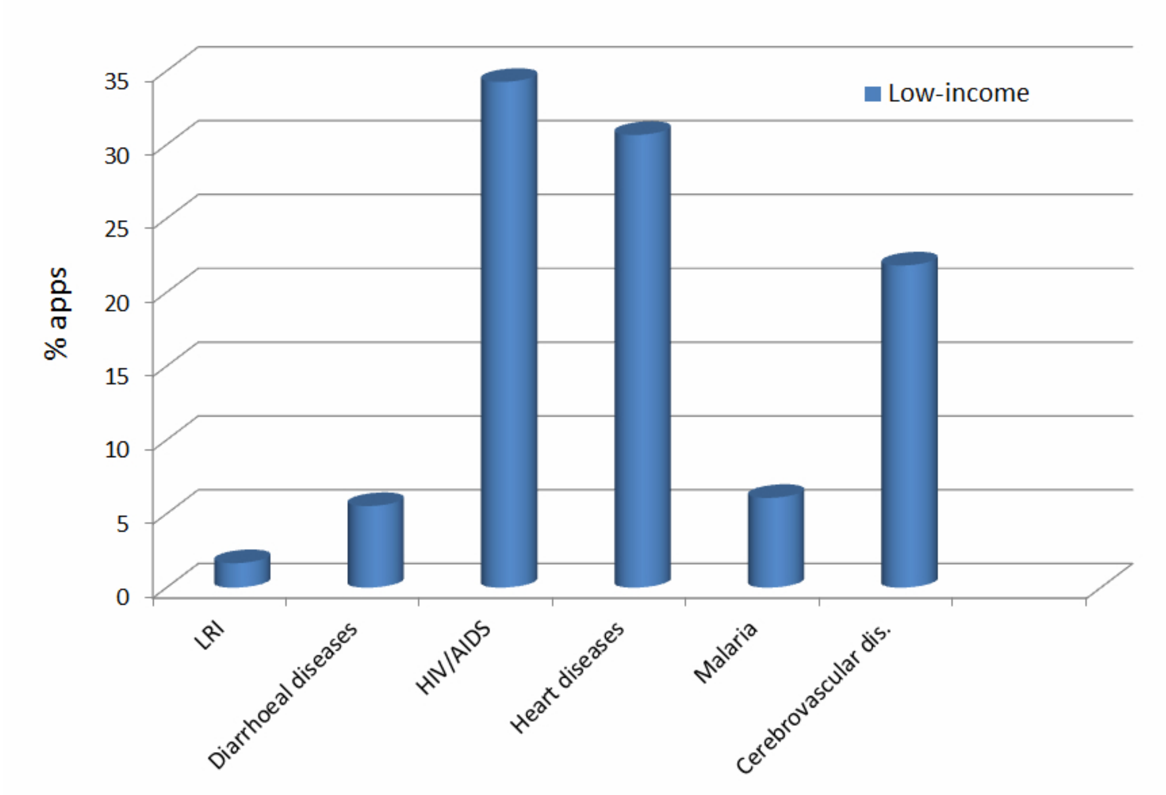


Figure 4. Percentage of apps (%) related to the top 6 causes of death of the middle-income zone.

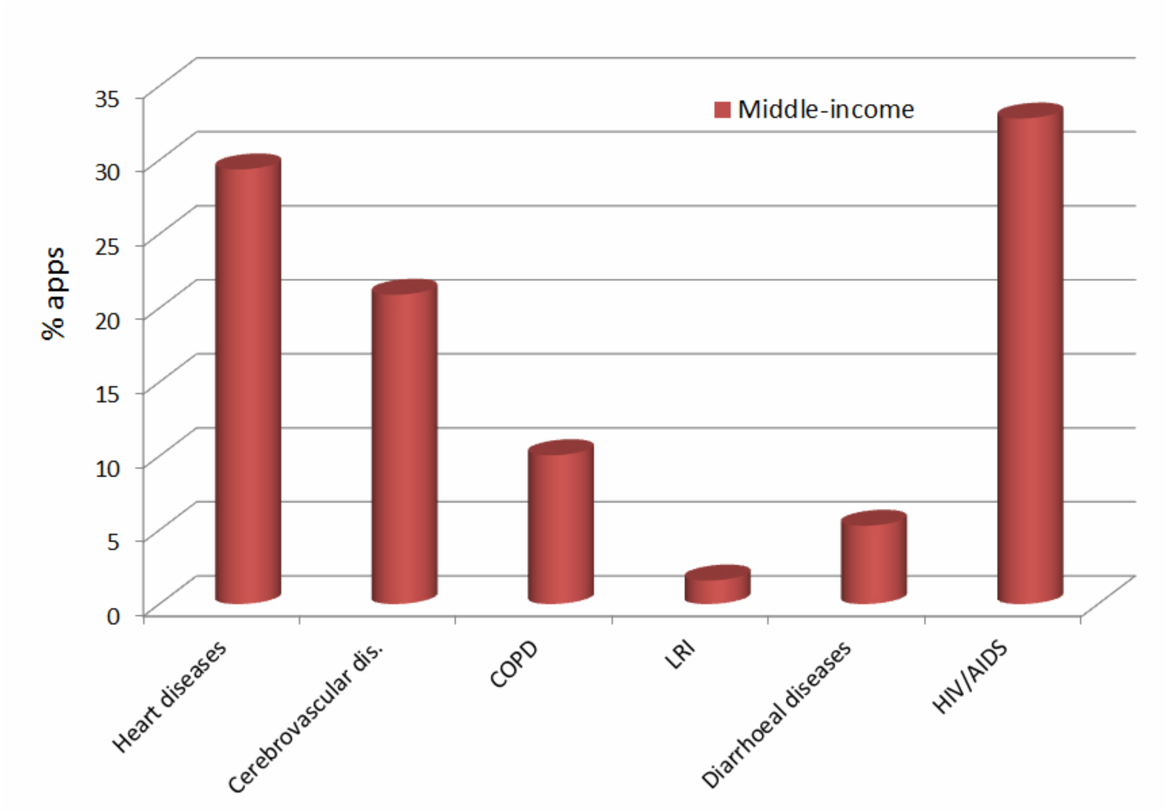
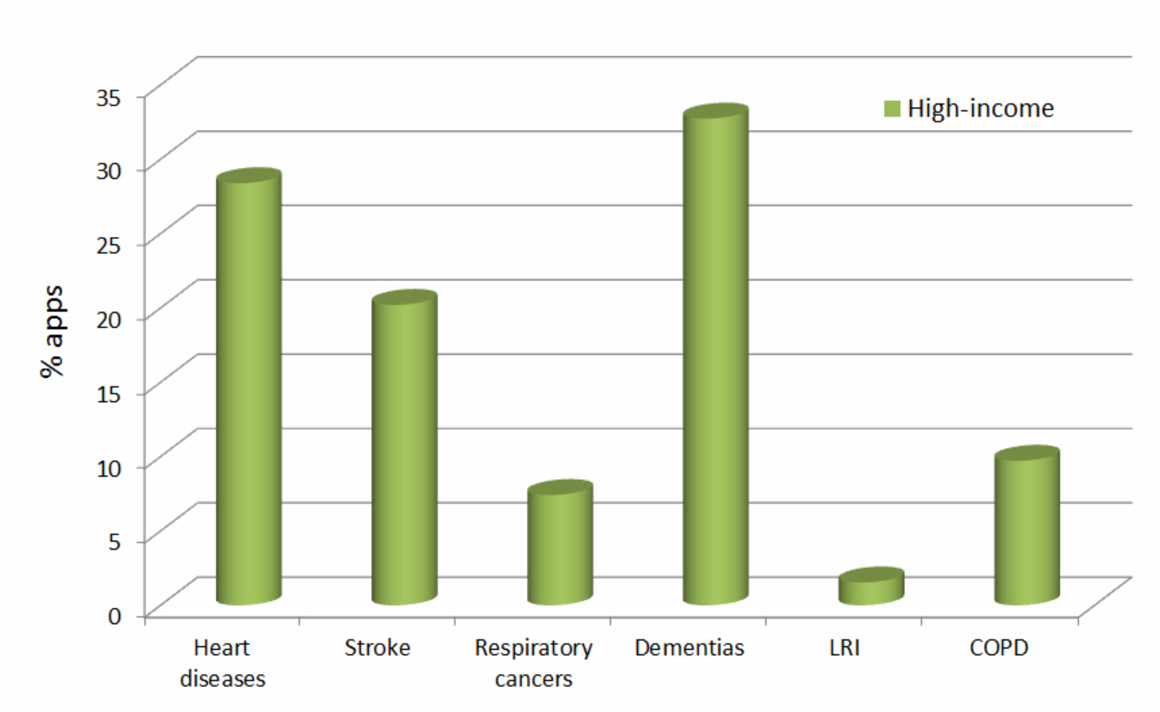


Figure 5. Percentage of apps (%) related to the top 6 causes of death of the high-income zone.



Discussion

Principal Findings

Some important conclusions can be obtained from the analysis of the results. Comparing the numbers of the literature review with the numbers of the commercial apps review, it is clear that there is more work done in the commercial field than in the research field. This is quite logical because the main objective of developers is earning money with their apps and, therefore, they focus on commerce. However, to create a good application, it is necessary to do some research [92], and this research can be a market study and/or an investigation about the application itself, including aspects such as the type of application, the necessity to cover, or the target public, among others. Unfortunately, what can be extracted from the results of this study is that most developers only do the market investigation or they do not publish the results of their studies while developing their apps. Contrasting the literature review with the commercial review, there are two differentiated groups. On one hand, there are four diseases with the highest percentage of work done in developing research and applications. These diseases are Alzheimer and other dementias, heart diseases, HIV/AIDS, and stroke and other cerebrovascular diseases. The numbers of the commercial apps review for the first three diseases mentioned before are similar and over 100 apps while for stroke and other cerebrovascular diseases the number of apps is much higher than the rest, which enforces the idea of two groups. On the other hand, the second group is formed by the rest of diseases, having much less work done in both research and commercial fields.

Another piece of information extracted from this comparison is that the position held by a disease in number of apps or papers found is similar in both reviews, with a maximum difference of two positions except for LRI with the fifth and ninth positions in the literature and commercial reviews, respectively. Hence, for the majority of the studied diseases, there is a concordance in the proportion of work done for each disease in both fields, which means that both researchers and developers generally agree on the importance given to each disease.

Contrasting the order of diseases according to the number of apps and papers and by mortality worldwide, there are some interesting issues. The most striking is that the diseases with more commercial apps, Alzheimer and other dementias, are not included in the top 10 causes of death worldwide. Therefore, why is there so much effort and work done in these illnesses? As exposed below, the answer is easy: Alzheimer and dementias are typical of high-income countries [27] where there is a social conscience of these illnesses and the population is very much aware of the consequences and dysfunctions that they cause, as shown by the great number of associations worldwide [93,94]. This reason, added to the facts that the majority of developers and developers groups are located in these countries [95-97] and designing apps for richer zones is more profitable, explains this issue.

The contrary occurs with LRI. Worldwide, this disease is the third leading cause of death, but the reviews carried out in this study show that its numbers do not correspond with this position (it is the fifth disease more researched and the last in commercial stores). This can be explained by several reasons: the first is that it is the first cause of death in low-income countries but it is not among the top 3 in middle- and high-income countries and, because developers are generally aware of these countries [95-97], this disease is not a priority for them. However, the previous reason alone is not enough to explain this case because LRI is the fourth and the fifth cause of death in middle- and high-income countries, respectively, above others such as HIV/AIDS, which has more apps and research.

Another important reason is that this disease is typical of children younger than 5 years old [40] and, as a result, developers have no reasons to create apps for LRI patients. One option could be the design of apps for parents, although people in developed zones are not very aware of this disease as they are with other illnesses such as HIV/AIDS [54,98] or diabetes [99], not giving it the importance it really deserves so it is underinvestigated. In addition, in developed zones, children are vaccinated against RSV [42], the most important cause of LRI. Thus, the combination of the previous reasons explains this situation.

There are other similar cases to the previous two, but not so extreme. Hence, as happens with Alzheimer, HIV/AIDS holds the second position in both reviews but it is only the sixth cause of death [54,98]. On the other hand, diarrheal diseases hold the fifth position in mortality but only the eighth and the last position in the commercial and literature review, respectively, quite similar to the case of LRI but more obvious, due to the fact that it is the second leading cause of death in children younger than 5 years old [49] and, in this case, it is not among the deadliest diseases in high-income countries [26,27].

Limitations

This study presents some limitations in the methodology followed for each review, typical for this type of revision [100]. The process of extracting the data presented a significant risk of uncertainty. Occasionally, the inclusion of a paper or an app in the study is not easy because the text is not clear and it can be misunderstood. To avoid this possible error, we enhanced the assessment process with independent verification. Thus, one author developed the search of literature papers, a second author developed the commercial review, and a third author inspected the results to check for possible errors.

The search results of the literature review were restricted to the past 10 years, from 2003 to the present day. This restriction did not affect the study because before 2003 there was a rather low number of smartphones and mobile devices, only dedicated to business, without commercial stores and health care applications as we know them today [101,102]. In addition, only papers dedicated exclusively to the disease searched were included in the study. Hence, there are papers dedicated to several diseases that can contain interesting information regarding the diseases studied dismissed.

Some limitations were found and addressed (if possible) in the commercial review. The results of the search of respiratory infections included some infections not specific to the lower respiratory system; hence, a discrimination of these results was necessary to select apps specific for lower respiratory infections.

Searching on iTunes, diarrheal disease provides no results, so in this case diarrhoea and diarrhea were used as search strings. The same was tried in the search of this disease on BlackBerry World but it returned no results. Because the disease name is so specific, no other terms could be used to obtain more results relative to it.

In the search of IHD, “ischemic heart disease” returned only 48 apps, very few for the most important cause of mortality. Hence, it was resolute to search only “heart disease” even though IHD is a specific type of heart disease. With this combination of words we found 353 apps, a much more significant number of apps. In addition to this, apps of diets or recipes were not included in the study, but those dedicated exclusively for cholesterol management were included because high cholesterol is a cause of heart malfunctions.

When inspecting the stores about trachea, bronchus, and lung cancers, apps for treatment or assistance in general cancer management that includes the searched cancer were taken into account. However, apps for quitting smoking were not studied despite the fact that smoking is the most important cause of lung cancer. We made this decision because there are other motivations to quit smoking, not only lung cancer, and those apps are not centered on the cancer itself.

In the case of Alzheimer and other dementias, there were a number of games designed for their prevention, although, as mentioned before, only those not included in the category of games were valid for the study (medical, health category). We did this because the majority of the found games included in the category games were not specifically designed for Alzheimer prevention and only took the commercial advantage of saying that they were useful for this purpose.

There were two issues with Google play. The first was that, in some searches, the store indicated that a certain number of results have been found but, while exploring the results pages, the last were blank. Because the number returned by the store and the real number of apps were different, we decided to use the last one, the number of applications shown. The other issue was that, when searching for stroke, the store returned more than 1000 results but only 480 apps were shown. In this case, the number used was the second one, 480. This last issue could affect our study because there are probably more apps apart from the 480 shown by Google. The current version of the store does not present these problems.

Another important limitation in the commercial review was the language used for the search strings. One of the objectives of this paper is to find and compare the existing apps for expressly mortal diseases in different income regions. Ideally, at least the most important low- and middle-income countries languages should have been used to obtain apps only developed in these languages. However, we only focused on the use of English, obtaining all the apps developed for this particular language, because it is the most extended and used worldwide. This barely affected the study of diseases typical of high-income countries because English is commonly used and extended there. Nevertheless, many results were shown in Spanish, because the stores detect the place where the search has been done, showing the apps and their summaries in the language of that place, if possible. In these cases, the apps were also included in the study, if relevant.

It is important to indicate that the search of IHD has actually become a search of “heart disease” in general, due to the lack of results with IHD alone in both reviews. Hence, we will talk about heart diseases instead of IHD. Nevertheless, it does not affect the study, because the applications found are for general heart diseases, including the one searched.

Conclusions

Comparing the number of apps and research done for disease with the position in cause of death for the three different zones, some interesting conclusions can be extracted. The leading cause worldwide and in middle- and high-income countries, heart diseases (IHD), is one of the most researched and with more apps, a logical fact because developers focus on typical diseases in high-income countries [98-100]. However, there are two diseases, the first and second of low-income countries, which have very little research and fewer commercial applications. These diseases are LRI and diarrheal diseases. The reason is the one mentioned previously: these illnesses are not common (diarrheal diseases) or there is no use of an app for the diseases (LRI), so that their research is not worthwhile, not to mention the fact that they are common in low-income zones where the technology for smartphones and tablets is not widespread [103,104] and, therefore, there are no market opportunities.

Another interesting case is what happens with HIV/AIDS, which is in the top 6 of low- and middle-income zones but even not being among the first 10 causes of death in high-income countries, it is the second disease with more research and applications. In this case, the illness is very popular not only in poor and developing zones but also in richer countries [101] in a way that, despite the fact that it is not one of the worst diseases in mortality in these rich countries, it has the attention of developers (as the numbers of this study show) and the population as a whole. At least, in this case all the countries can feature these apps for HIV/AIDS if they have the means needed.

The most curious case is the one with trachea, bronchus, and lung cancers. They are the third cause of death in high-income countries, but are included in the least researched diseases with regard to apps. The reason is not clear, because cancer in general is a common matter and there is a huge amount of information and applications about it. In fact, the search for “cancer” on the App Store returns 896 apps and 500 on Google play. Moreover, specifically these types have also an important social conscience principally for being consequences of smoking [63,64]. Therefore, it can be considered a good opportunity for developers to fill this empty space in mobile apps for health care.

Focusing on the types of the predominant apps for each disease, there is a common one for all of them: the informative apps, which can be for patients as well as for health care professionals. Excluding these apps, the rest have different purposes depending on the disease. Hence, developers have tried to take advantage of the characteristics of each illness. They centered on prevention in diseases with no cure or with a cure based on medications where no mobile phone aid is needed such as Alzheimer and dementias, with games useful for their prevention; and malaria, with mosquito-repellant apps. There are also several apps for HIV/AIDS focused on the prevention with educational apps for the public (and others for patients). Health care professionals are the objective of the apps designed for LRI, stroke, and lung cancer, which offer aid in the diagnosis or the assessment of the stage/status of the diseases. Finally, in the cases of diarrhea and COPD the majority of apps (excluding the informative ones) are designed for treatment: personal remedies for diarrhea (mild diarrheas), and COPD trackers as well as educational apps for the use of inhalers.

Finally, the enormous difference in the number of applications found in the distinct stores is surprising. Google play and iTunes are clearly the ones with more apps followed by far by Windows Phone Apps+Games and BlackBerry World, as previously observed [71]. The case of BlackBerry is unusual: in November 2012, it had a market share of 7.3% [72], but it barely has applications for the diseases searched. On the other hand, Microsoft Phone had less market share (3% in November 2012 [72]) but more apps, yet much less than the number of apps of Google play and iTunes. As a result, a great number of users of BlackBerry and Windows Phone would abandon their phones, changing them for others that have the maximum number of apps available. Indeed, this is already happening [72] and can be a reason for the lack of apps for Windows Phone and BlackBerry, because developers are discouraged from creating apps for these stores.

For future work, several things can be done. It is possible to develop a mobile app for LRI because of the absence of apps related to it and its importance in mortality (third cause of death worldwide). It can include the most common infections such as bronchitis or pneumonia. Another possibility is to fill the empty space in mobile apps related to the trachea, bronchus, and lung cancers, for example developing an assistive and informative application for aiding patients who are being treated for these cancers.

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Conflicts of Interest

None declared.

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Abbreviations

COPD: chronic obstructive pulmonary disease
CVD: cardiovascular disease
DALY: disability-adjusted life year
HIV/AIDS: human immunodeficiency virus /acquired immunodeficiency syndrome
IHD: ischemic heart disease
LRI: lower respiratory infections
NIH: National Institutes of Health
PDA: personal digital assistant
RSV: respiratory syncytial virus
WHO: World Health Organization

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Review

Mobile Apps in Cardiology: Review

Borja Martínez-Pérez[1*], MSc; Isabel de la Torre-Díez[1*], PhD; Miguel López-Coronado[1*], PhD; Jesús Herreros-González[2*], PhD

[1]University of Valladolid, Department of Signal Theory and Communications, and Telematics Engineering, University of Valladolid, Valladolid, Spain
[2]Institute of Biomedical Engineering and Health Technology, 2IByTS, Catholic University of Murcia, Murcia, Spain
[*]all authors contributed equally

Corresponding Author:
Borja Martínez-Pérez, MSc
University of Valladolid
Department of Signal Theory and Communications, and Telematics Engineering
University of Valladolid
Paseo de Belén, 15
Valladolid, 47011
Spain
Phone: 34 983423000 ext 3703
Fax: 34 983423667
Email: borja.martinez@uva.es

Abstract

Background: Cardiovascular diseases are the deadliest diseases worldwide, with 17.3 million deaths in 2008 alone. Among them, heart-related deaths are of the utmost relevance; a fact easily proven by the 7.25 million deaths caused by ischemic heart disease alone in that year. The latest advances in smartphones and mHealth have been used in the creation of thousands of medical apps related to cardiology, which can help to reduce these mortality rates.

Objective: The aim of this paper is to study the literature on mobile systems and applications currently available, as well as the existing apps related to cardiology from the leading app stores and to then classify the results to see what is available and what is missing, focusing particularly on commercial apps.

Methods: Two reviews have been developed. One is a literature review of mobile systems and applications, retrieved from several databases and systems such as Scopus, PubMed, IEEE Xplore, and Web of Knowledge. The other is a review of mobile apps in the leading app stores, Google play for Android and Apple's App Store for iOS.

Results: Search queries up to May 2013 located 406 papers and 710 apps related to cardiology and heart disease. The most researched section in the literature associated with cardiology is related to mobile heart (and vital signs) monitoring systems and the methods involved in the classification of heart signs in order to detect abnormal functions. Other systems with a significant number of papers are mobile cardiac rehabilitation systems, blood pressure measurement, and systems for the detection of heart failure. The majority of apps for cardiology are heart monitors and medical calculators. Other categories with a high number of apps are those for ECG education and interpretation, cardiology news and journals, blood pressure tracking, heart rate monitoring using an external device, and CPR instruction. There are very few guides on cardiac rehabilitation and apps for the management of the cardiac condition, and there were no apps that assist people who have undergone a heart transplant.

Conclusions: The distribution of work in the field of cardiology apps is considerably disproportionate. Whereas some systems have significant research and many apps, other important systems lack such research and lack apps, even though the contribution they could provide is significant.

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KEYWORDS
apps; cardiology; heart; m-health; mobile applications

Introduction

According to reports from the World Health Organization, an estimated 51 million people died in 2008 from any type of disease, communicable and noncommunicable, with the latter causing the most deaths. Among them, the worldwide leaders in mortality are cardiovascular diseases (CVDs), with 17.3 million deaths in 2008 alone, representing 30% of all deaths globally. Moreover, these deaths occur in a disproportionate way, with more than 80% occurring in low- and middle-income countries. Regrettably, no better outlook is expected, since it is estimated that more than 23 million people will die annually from CVDs by 2030 [1-5].

Ischemic heart disease (or coronary heart disease) is especially fatal among CVDs, responsible for 7.25 million deaths in 2008. Further, there are more heart-related diseases with a significant fraction of deaths, such as hypertensive heart disease and inflammatory heart disease. In fact, more people die of heart malfunction than of AIDS and all cancers combined. The contribution of these diseases to disabilities is notable—62,587 million Disability-Adjusted Life Years (DALYs) are due to coronary heart disease. These data mean massive costs to the economy of all countries, being estimated at US$448.5 billion in the United States alone in 2008 [2,6-8].

In light of such statistics, it is imperative that we reduce these numbers, not only in health care environments such as hospitals or primary health care facilities, but also in patients' homes and workplaces. To meet this objective, mHealth, defined as "the use of mobile computing and communication technologies in health care and public health" [9], is of utmost importance. For that same reason, the latest advances in mHealth [10-13] and wireless technologies [14-16] have been used, resulting in improvements in several different aspects, from health to financial [17,18].

To aid in this initiative, it is important to acknowledge the use of smartphones and tablets as devices that have become essential to users in recent years. In numbers, there were more than 6 billion mobile subscriptions and more than 1.7 billion mobile phones sold in 2012 alone, of which 712.6 million were smartphones [19-21]. The International Data Corporation (IDC) estimated 70.9 million shipments of tablets globally in 2011 and predicted 117.1 and 165.9 million in 2012 and 2013 respectively [22]. With such growth, it was only a matter of time before the use of these devices would be adopted for mHealth, in the form of mobile applications or apps. Focusing only on the most important app stores, in terms of the market share of smartphone operating systems [23,24], the App Store [25] for Apple iOS has close to 20,000 apps in the category of Health & Fitness and more than 14,000 in Medicine. Android's Google play [26] has more than 11,000 apps in the Health & Fitness section and roughly 5000 in the Medical apps section [27].

The aim of this paper is to conclude research on mobile applications for the most important diseases and health conditions, which we began previously with a study about mobile applications for the most prevalent health conditions [28]. This time we focus on the deadliest illness: heart disease.

The main objective of this paper is to study the literature on existing mobile systems and applications, as well as cardiology apps currently available on the cited app stores. In the first part of the research, a review of published articles was performed across several systems and databases and was complemented in the second part with a search of apps in the Apple and Google app stores. The objective was to classify the results in order to see the progress as well as the lack of applications and systems, focusing specifically on commercial apps (ie, those apps available on app stores). Other secondary objectives were to obtain information regarding the prices of these apps and their target users. Since there are no published reviews on this specific topic, the results may be of considerable interest for developers and researchers wanting to investigate further or to create a new app.

Methods

Two reviews were developed and took place up to May 2013. The first was a review of existing mobile systems and applications in the field of cardiology found in the literature, and the second, a study of commercial apps related to cardiology found in the leading app stores.

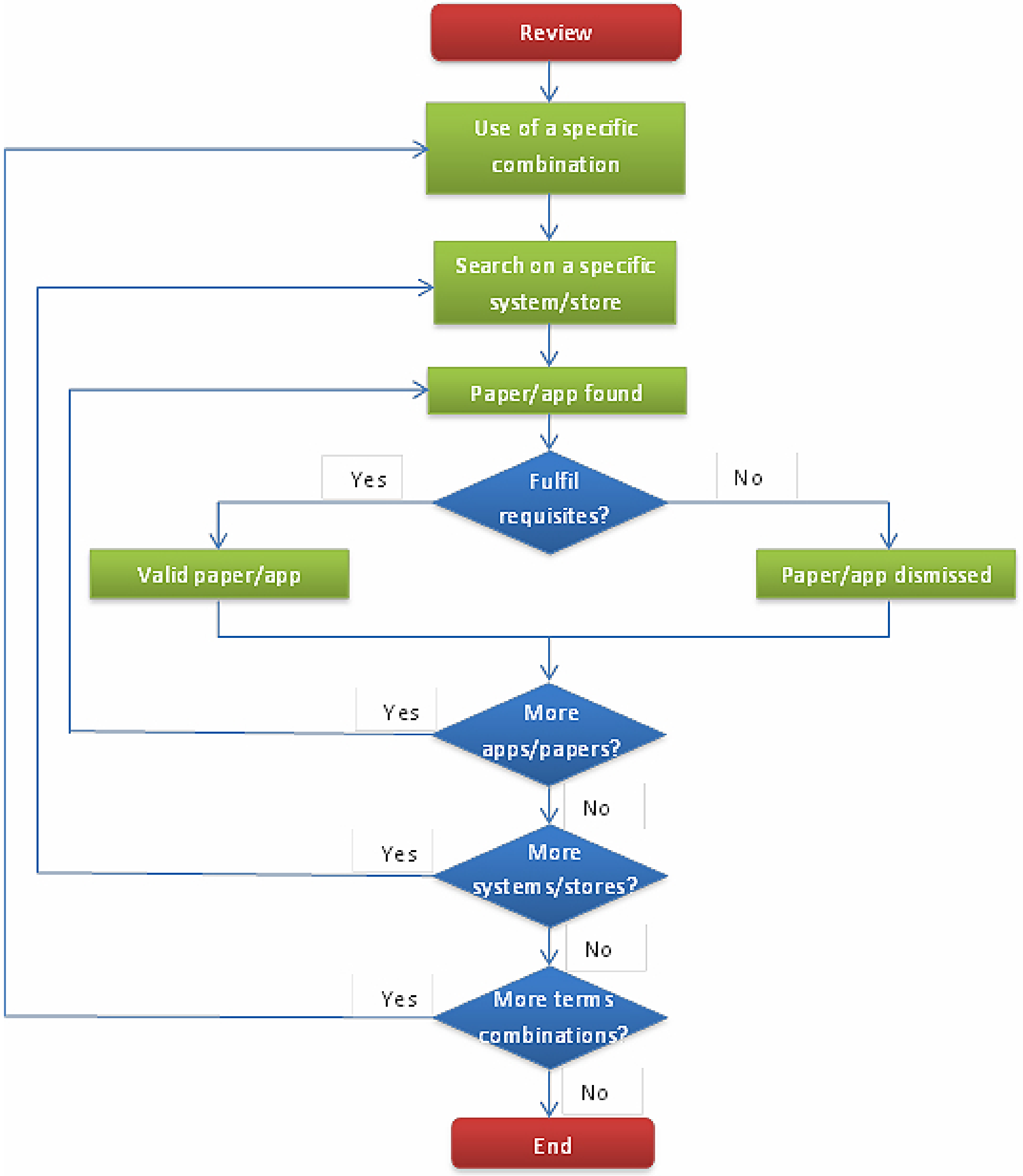
Review of Mobile Systems and Applications for Cardiology in Literature

To perform the literature review, the following systems and databases were used: Scopus, IEEE Xplore, Web of Knowledge, and PubMed. The methodology followed is presented in Figure 1 and also applies to the commercial apps review. In this section, the objective was to search for relevant papers in different systems. The following combinations of search terms were used in the metadata field: "term1" AND mobile AND (application OR app); "term2" AND mhealth; "term2" AND smartphone; and "term2" AND "mobile phone", where "term1" and "term2" could be different words. The words used for "term1" were heart disease, heart failure, infarction, arrhythmia, heart attack, coronary disease, angina, fibrillation, cardiology, hypertension, heart transplant, and heart transplantation. For "term2", the terms used were cardiology and heart.

The results were limited to the last 10 years, from 2003 to the present day, and the eligibility requisites used were the following: only papers published originally in English were studied. Publications about mobile systems or applications not focused on cardiology or designed for more than 3 different fields were dismissed, but if the application was intended for 3 disciplines or fewer with being cardiology one of them, then it was included in the review. Similarly, papers regarding systems for many diseases (not only cardiac diseases) were rejected. Articles with algorithms for classification, detection, compression, encryption, or authentication of ECG data (or other types of heart signs) were studied, but publications about the possible influence of the electromagnetic fields irradiated by mobile phones in the heart rate or in implanted cardiac devices were dismissed.

When the selection of papers was finished, the authors convened in order to classify the articles in different categories by reading their abstracts as well as the whole article when required. Once this process was completed, a revision was done and similar categories were merged to obtain a more condensed classification.

Figure 1. Flow chart of the methods followed in the literature and the commercial reviews.



Review of Apps for Cardiology in Commercial App Stores

The second review was a search of apps related to cardiology in the two leading commercial stores for smartphones [23,24]: the Apple App Store and Google play.

The methodology used in this review is the same used in the previous one, shown in Figure 1, although in this case exploring apps in commercial stores, instead of papers in databases. The search terms used for both stores were heart and cardiology. The eligibility requisites used for this review were the following: apps not in English or in the language of the place where the search was executed (Spanish) were dismissed, the same as those with their summary in a different language from the two mentioned. Only applications focused on cardiac issues were studied. Games, music, apps for cholesterol management or losing weight, apps for animals, and apps for congresses or conferences were dismissed, but apps related to hypertension were included in the study.

In the App Store, since the apps are separated for iPod and iPhone and for iPad, only the first ones were searched, although in many cases they were also available for iPad. During the search on Google play, some problems arose. When searching by “cardiology” or “heart”, the store indicated that there were at least 1000 results, although it showed only 480. Google was asked about this discrepancy and the issue is still under investigation; hence, it was decided to use other search words in order to obtain the highest number of apps related to cardiology in this store. These words were infarction, heart attack, heart failure, heart disease, fibrillation, coronary heart, angina, and arrhythmia. Additionally, in some of these new searches on Google play, it was indicated that a certain number of results has been found but, when exploring the pages of the results found, the last pages (usually between one and three) were blank. This issue did not affect the review since the apps studied are the ones shown, although it is not known if there were more apps that were not visible due to this error.

Once the selection of cardiology-related apps was complete, the authors convened again to sort the apps by their purpose in different types, by reading the summary and explanation given by the stores and downloading them when the explanation specified was not clear enough. In these cases, the smartphones used were an iPhone 4 if the app was designed for iOS and a Samsung Galaxy S SCL GT-I9003 in the case of an app for Android. Finally, revisions were done in order to shorten the classification, similar to the process followed in the literature review.

Results

Mobile Systems and Applications for Cardiology in Literature

A total of 406 relevant papers were found in all the databases and systems used. The classification of the papers by their content is shown in Table 1, which also shows the number of articles for each category.

In Figure 2, the percentage of papers found by their year of publication, from 2003 to 2012, is shown. It can be seen that the publications increased every year until 2011, decreasing slightly in 2012.

Apps for Cardiology in Commercial Stores

A total of 710 relevant apps were found in the App Store and Google play, although we note that some apps are available in both stores. In this study, these apps are counted separately. Hence, 439 apps are available for iOS and 271 for Android. The majority of the apps for iOS are found in the categories of Medicine (303) and Health & Fitness (111), whereas the remaining are included in Utilities (8), Education (7), Entertaining (3), Lifestyle (2), Sports (2), Books (1), Reference (1) and Social network (1). The apps for Android are found in the categories of Medical apps (188), Health & Fitness (65), Education (8), Lifestyle (7), and Books & Reference (3). The classification of these apps sorted by their functions and in decreasing order are shown in Table 2.

If the classification was performed taking into account the target public to whom the app is destined, another sort was conducted. Figure 3 shows the number of apps sorted by target users for each app store.

To understand Figure 3, it is necessary to explain the difference between the “general public” and “everyone”. General public is used for common users—normal people not necessarily affected by heart disease. It does not include health care professionals. On the other hand, everyone includes all groups. It is used for apps intended for a specific type of user, such as medical students but that can also be used by other users, such as professionals or the average person for example.

Finally, statistical values on the prices of the apps separated by commercial store are summarized in Table 3. For the mean, mode, and median values, the study is divided into two groups: one group shows all the apps found and the other shows only the apps that are not free.

Table 1. Classification of the results of the literature review.

Type of system/application	Articles
Vital signs monitoring system	55
ECG (electrocardiography)/cardiac signal detection/classification algorithms	44
Heart monitoring system	37
ECG/heart monitoring system trial/evaluation	28
Remote heart monitoring system	25
Heart monitoring system with alerts	17
Cardiac rehabilitation mobile system	16
ECG data transmission	14
Blood pressure measurement/monitor system	13
Remote management/monitoring of implanted pacemakers/cardiac devices	11
Teleconsultation system	10
Remote and local heart monitoring system	8
Exercising/sports related heart monitoring system	7
Innovative heart rate monitor	7
Arrhythmia detection system	7
Sensors evaluation/state of the art	6
Surveys/states of the art of cardiology systems	5
Heart rate & blood pressure monitoring system	5
Remote heart monitoring system with alerts	5
Atrial fibrillation detection system	5
Heart failure detection system	5
Phonocardiography mobile system	5
Remote and local heart monitoring system with alerts	4
Breath monitoring system	4
ECG data compression technique	4
Automatic music selector to maintain a target heart rate	4
Alerts and location of heart attacks	4
CPR instructions through mobile phone trial	4
CPR instructions/reminder through mobile phone	4
Applications for promotion of healthy behaviors	4
System for measuring/reducing stress	3
Personal lifestyle and health management system	3
Fetal heart monitoring system	3
ECG data encryption/authentication/privacy	3
Cardiac rehabilitation mobile system trial	3
Exercising/sports related heart monitoring system evaluation	3
Mobile medical applications for chronic diseases	2
Pocket-size images interpretation	2
First aid/resuscitation app evaluation	2
Apps for hypertension in smartphones	2
Emotional states detection through measuring heart rate differences	2

Type of system/application	Articles
Weight control in high-risk heart failure population	2
Medications management	2
Telemetry-based system for monitoring rats’ vital signs	1
Heart attack self-test app	1
Trial for comparing follow-up of hypertensive patients	1
Study about the correlation music-heart rate variability	1
App for improving basic life support (BLS)	1
Non-invasive tissue classifier	1
Share of vital signs in a social network	1

Figure 2. Percentage of papers found per year of publication.

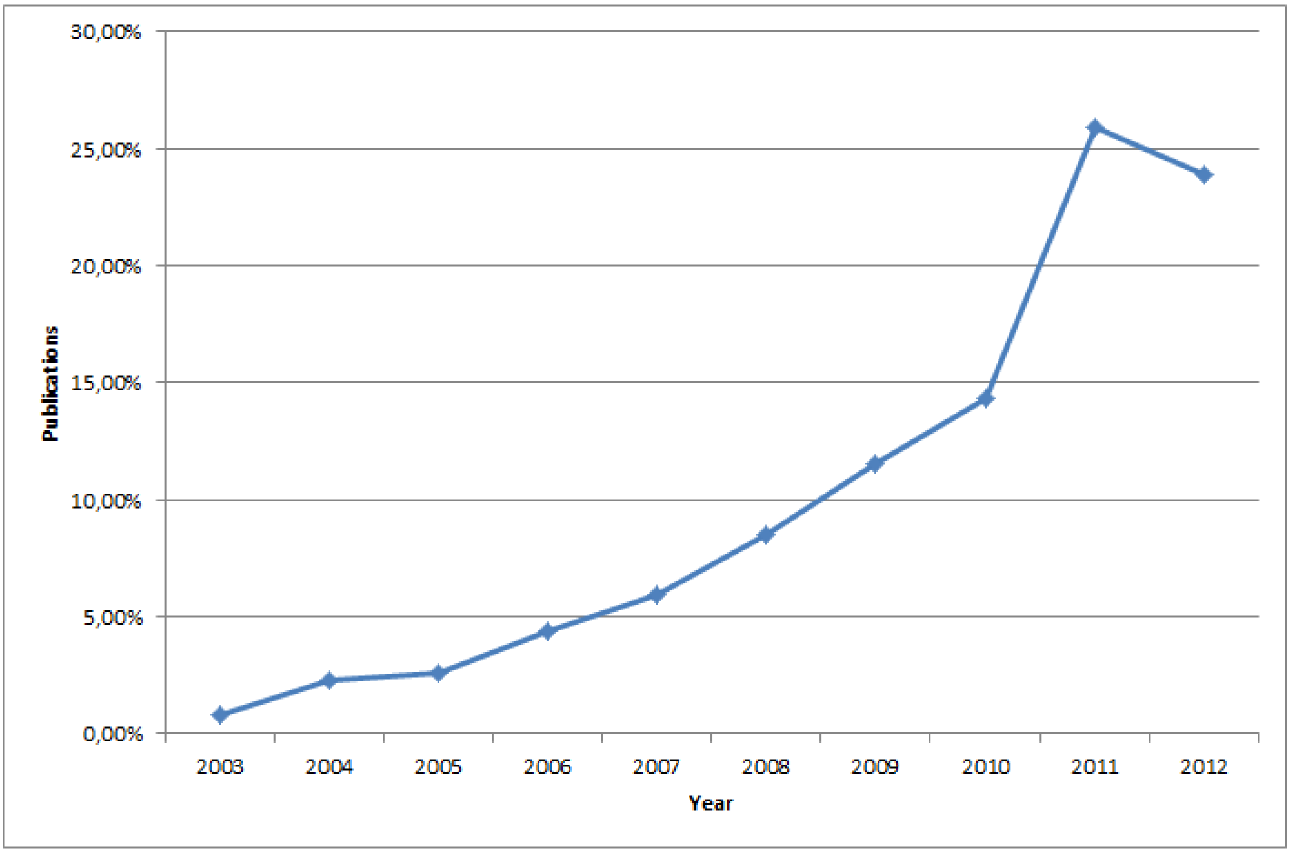


Table 2. Classification of apps in the commercial review by function.

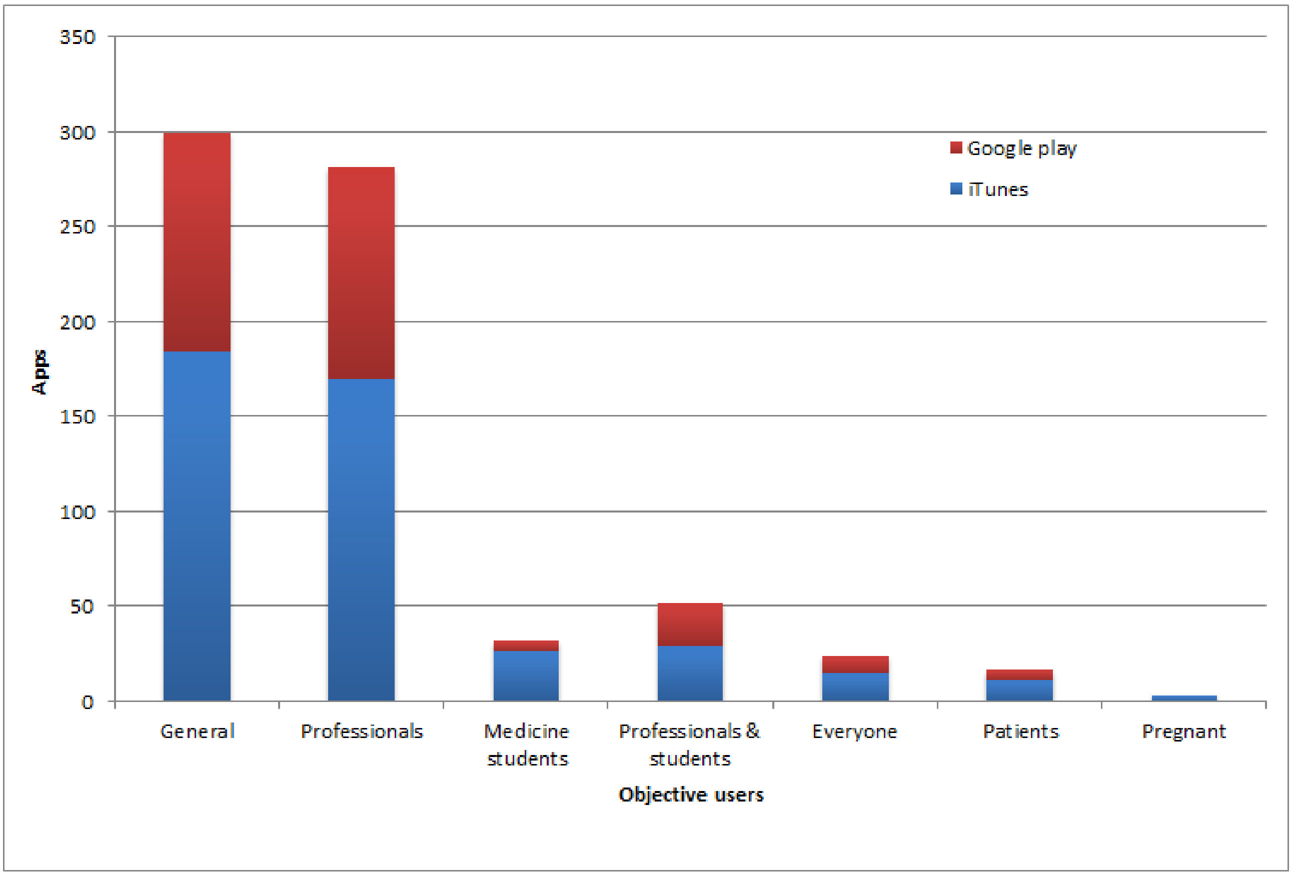
Type of app	Number
Heart rate monitor	94
Algorithm/calculator/predictor	85
Informative guide	41
Educational ECG/interpretation aid of ECG	37
News/journal	34
Blood pressure tracker	30
External devices heart rate monitor	22
CPR (cardiopulmonary resuscitation) instructions	21
Educational anatomy	17
Medicine students education	17
Guide/book	17
Health tips	17
Diagnosis & treatment guidelines	14
Echocardiography reference	14
Professionals & students education	14
Medicine exam preparation	13
General education	11
Diagnosis aid	10
Animated guide	9
Heart sounds reference	9
Blood pressure & heart rate monitor	9
Cardiology medical reference	8
Medical images reference	8
Catheter reference	8
Guide of professional commercial devices	7
Stethoscope/educational stethoscope	7
AED (automated external defibrillator) location	6
Professionals education	6
Clinical trials	6
ECG cases reference	5
Hypertension reference/guidelines	5
Procedures in emergency cases	5
Patients’ history/ECGs/images	4
Surgeon aid/training	4
Professionals connections, knowledge/cases share	4
Angiography reference/guide	4
Auscultation reference	4
Heart rate monitor for exercising	4
Fetal heart rate monitor/interpretation	4
Heart rate calculator	4
Ultrasound video reference	4

Type of app	Number
Resuscitation instructions/guide	4
Educational/explanations for patients	3
ECG sending	3
Log procedures	3
Diseases prevention guide	3
Heart rate monitor with external devices for exercising	3
Professionals guidelines	3
Audio reference	2
ECG signal transformer	2
Location of cardiac emergencies	2
Blood pressure measurement with external devices	2
CPR and AED instructions	2
Prescribing drugs	2
AED training	2
Pulse measurement aid	2
Hospitals	2
Instructions/training CPR & AED location	2
Perfusion reference	2
Arrhythmia reference	2
Acute coronary syndrome reference	2
Stent guide/reference	2
Prosthesis guidelines	1
Teleconsultation	1
Upload ECG from a commercial monitor	1
Medications reminder	1
Treatment guide	1
Stand-alone or with external device heart rate monitor	1
Auto-diagnosis	1
Cardiac rehabilitation guide	1
Anesthesia management	1
Social network	1
Atrial fibrillation guidelines	1
AED training with simulation of external device	1
Blood pressure prevention & treatment exercises	1
Condition management	1
Congenital heart defects reference	1
Clinical examination guide	1
Blood pressure measurement	1
Driving guidelines for cardiac patients	1

Table 3. Statistical data on the prices of apps in the commercial review.

	Min.	Max.	% free apps	Mean		Mode		Median	
				Total	Not free	Total	Not free	Total	Not free
iTunes	0	129.99	43.28	2.89	5.10	0	0.89	0.89	1.79
Google play	0	100	49.82	3.45	6.87	0	1.04	0.71	2.17

Figure 3. Classification of the apps of the commercial review by target users.



Discussion

Principal Findings

In light of the results presented in the previous section, several interesting findings can be extracted. Focusing on the literature review, the majority of the 406 articles found are about systems that normally use a mobile phone or smartphone and only a small percentage concerns mobile apps exclusively. In addition, as Table 1 shows, 4 of the first 5 types of applications with more papers are directly related to heart monitoring systems (including vital signs) while the remaining one is related to algorithms for selection/classification of ECGs or other measurable heart signs. At the same time, other different types of heart monitoring systems can be found in the classification. There were 198 papers about those systems, which is almost half of all the publications found. This indicates that the most researched area associated with cardiology is related to mobile heart monitoring systems and the techniques involved in the classification of heart signs in order to detect malfunctions.

An example of a heart monitoring system is the one proposed by Yap et al (2012), which uses a chest-belt wireless ECG measurement system in combination with an Android app for monitoring ECG in real time [29]. In this case, there is an app involved in a whole system, but, as mentioned above, there are few articles focused exclusively on apps, such as the one written by Leijdekkers and Gay (2008) about a heart attack self-test app that allows possible victims to assess whether they are suffering an infarction [30]. De Vries et al (2013) evaluated the actual use and goals of telemonitoring systems [31], whereas Seto et al (2012) developed a randomized trial of mobile phone-based telemonitoring systems [32] to examine the experience of heart failure patients with these systems [33]. An algorithm for improving the classification of ECGs was developed by Jekova et al (2011), which scores the noise corruption level of ECG data by evaluating several features [34]. It is important to indicate that most of these systems cited were designed for patients' use with the knowledge and consent of their professional caregivers, since they have an important role in the correct functioning of the applications, either monitoring remotely the patients' heart or receiving alarms when a heart problem occurs.

Other systems with a number of papers are the following: cardiac rehabilitation mobile systems [35,36], extremely important in the recovery of heart attacks or in their prevention in people with heart problems [37,38]; systems for measuring blood pressure combined or not with heart rate monitors [39,40], in order to avoid possible problems derived from hypertension (or raised blood pressure), an important risk factor for coronary heart disease or ischemic stroke and indirectly the cause of 9.4 million deaths every year [41,42]; and systems for the detection of heart malfunctions, sometimes focused on certain problems such as arrhythmia or atrial fibrillation [43] and sometimes considering more than one disease [44]. Other important contributions are done in the remote management or monitoring of cardiac devices such as pacemakers, in order to assess their correct operation and to perform periodic checks, which is currently very common in modern health care facilities [45].

Examining the dates of publication of these papers, shown in Figure 2, it is clear that research in mobile systems in the field of cardiology has gained more and more importance in recent years, beginning in 2003 and with many more published articles by 2011 and 2012. This fact shows that the part of cardiology associated with mobile technology has become the recent focus of investigations—quite logically since cardiovascular diseases and especially heart diseases are the leading causes of death worldwide.

In the review of cardiology-related apps, many outcomes were observed. The first notable conclusion from classification (Table 2) is the difference between the first two positions (ie, heart rate monitors and calculators) and the rest, when taking into account the number of apps for each category. There are far more apps for heart rate monitoring and medical calculators or predictors than for informative guides, which is in the third position. In addition to these heart monitoring apps, there are those that use an external device as well as those focused on exercising. Figures 4 and 5 show snapshots of two examples of heart monitoring apps: Runtastic Heart Rate & Pulse Monitor [46] for iOS and Instant Heart Rate [47] for Android. Of the more than 20 apps, we found the following types: apps for ECG education and interpretation, cardiology news and journals, blood pressure tracking, heart rate monitoring using an external device, and apps with instructions about CPR. These categories equal a total of 364 apps, which is more than half of the total apps found.

Despite the fact that the classification shown in Tables 2 and 3 is subjective, we believe we obtained the most realistic classification, performing several iterations until arriving at the final one. As a result, those categories with similar patterns and characteristics have been merged, whereas others with unique features were not, in order not to lose information in the process. As a result, there are many categories with few apps, some of them highly useful and interesting, such as apps related to resuscitation procedures, including apps with CPR and/or AED instructions, essential for properly performing a resuscitation and, hence, saving lives. There were also AED location apps, which indicate the position of nearby AEDs for cardiac emergencies with the help of the GPS (Global Positioning System) included in every modern smartphone. Other compelling apps are those designed to locate cardiac emergencies, through the help of the users, either sending an emergency alarm or receiving it in order to assist them on site. The majority of these types of apps are free; therefore, their use has no additional cost to the user. Since the outcomes they can achieve are significant (eg, saving the life of a person suffering a heart attack), it would be better if there were more available and they were also free.

There are other categories with very few apps (or even no apps), which could provide significant assistance and help. Examples are guides for cardiac rehabilitation and apps for the management of a cardiac condition, with only one app of each type.

Since a rehabilitation program for people who have suffered or suffer heart problems (or have had a heart surgery) is vital [37,38] in order to avoid more worrisome consequences, it would be beneficial for these individuals to have a guide with exercises and instructions for complete rehabilitation of their hearts. Similarly, apps for the management of heart conditions can be useful for people suffering congenital heart defects involving arrhythmia, angina, fibrillations, etc. In addition to this, it is surprising that there are no apps for aiding people who have undergone a heart transplant, since guidelines, exercises, or even medication management would be of help.

Figure 3 shows the numbers of apps for a specific target public, where it is clear that the users preferred by developers are general users and health care professionals. Typical apps for the general public are heart rate monitors, blood pressure trackers, apps with health tips, educational apps, and resuscitation (CPR and AED) guides. Common apps for professionals are calculators and predictors useful for diagnosis or treatment, specific educational apps and references (angiography, catheters, surgery, etc), and guides, books, and apps for assisting in the diagnosis. Educational apps about medicine and apps for the preparation of medical exams are usually designed for students. The apps intended for common people, medical students, and professionals (category "Everyone") are usually educational and informative apps while typical apps for patients are those for the care of their condition, some with calculators to assess their state and informative guides. The apps for pregnant women are fetal heart rate monitors. Here we note that there are few apps designed exclusively for patients. Nevertheless, there are many general informative applications that can be used by patients; hence, these apps can compensate for the lack of specific apps for patients. However, a preferable option would be the creation of a specific app for the treatment of a determined condition in order to help the affected in a more appropriate way.

Figure 4. Snapshot of Runtastic Heart Rate.

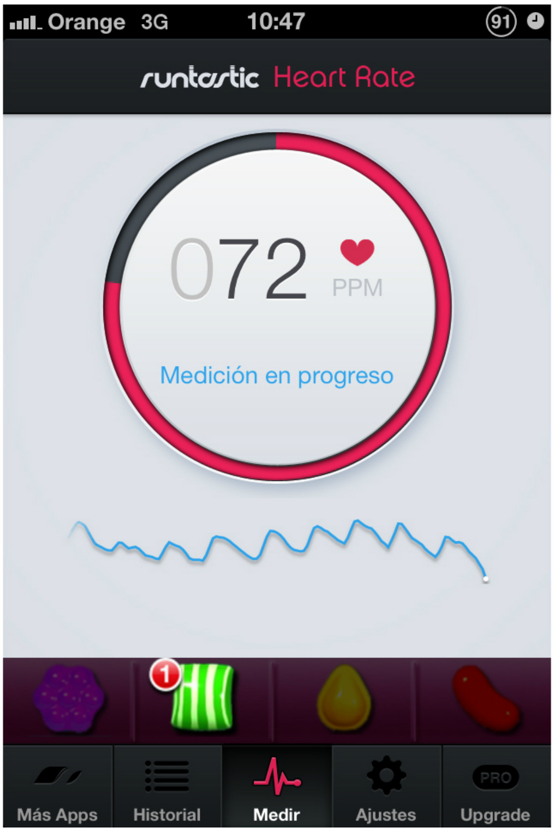
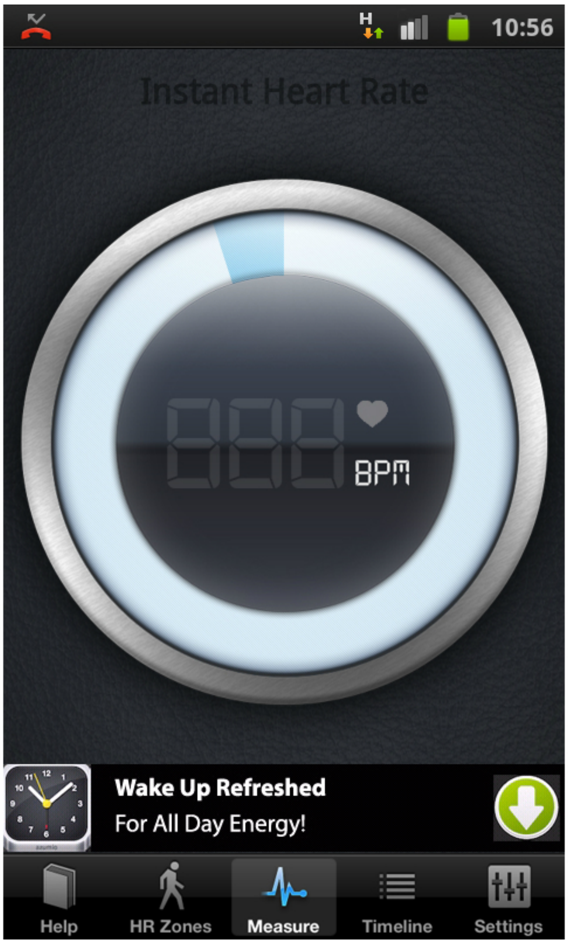


Figure 5. Snapshot of Instant Heart Rate.



Conclusions

Comparing the results for each store, several conclusions can be made. First, there are more apps related to cardiology in the App Store, despite the fact that Android is more prevalent than iOS [23,24]. Figure 3 shows that the numbers related to target users obtained for Apple are consistent with the numbers for Google play, suggesting that the developers for both stores have similar approaches and ideas. The data shown in Table 3 reveal interesting findings. Google play exceeds the App Store only in the number of free apps. Despite the fact that the highest-price app on the App Store is more expensive than the corresponding on Google play, the mean price is lower than the one in Google play, whether free apps are included or not. This was unexpected, since there is a collective belief that iOS devices (especially iPhones and iPads) are more exclusive (usually used in the business environment) and expensive than Android devices [48,49], and their apps are also considered to be higher quality than apps for Android [27,50]. This seems not to be the case in the cardiology field.

There are various lines of investigation for further research. New applications are needed for the management and monitoring of specific cardiac conditions, designed for the patients affected by them, since there are few currently available. The development of applications with this aim could be rather valuable. Another potential field of research could be the creation of an app with guidelines and information for people who have undergone a heart transplant. Such an app could assist them in their new condition and facilitate their new state. Another field to supply is related to resuscitation guides and instructions. Although there are several useful apps with such functions, the creation of an app with different functionalities parallel to the existing ones could be another beneficial field of research, perhaps developing the idea of the location of cardiac emergencies for people trained in resuscitation skills.

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Conflicts of Interest

None declared.

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Abbreviations

AED: automated external defibrillator
BLS: basic life support
CPR: cardiopulmonary resuscitation
CVDs: cardiovascular diseases
DALYs: disability-adjusted life years
ECG: electrocardiography
GPS: Global Positioning System
IDC: International Data Corporation
WHO: World Health Organization

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Mobile Clinical Decision Support Systems and Applications: A Literature and Commercial Review

Borja Martínez-Pérez · Isabel de la Torre-Díez · Miguel López-Coronado · Beatriz Sainz-de-Abajo · Montserrat Robles · Juan Miguel García-Gómez

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Abstract The latest advances in eHealth and mHealth have propitiated the rapidly creation and expansion of mobile applications for health care. One of these types of applications are the clinical decision support systems, which nowadays are being implemented in mobile apps to facilitate the access to health care professionals in their daily clinical decisions. The aim of this paper is twofold. Firstly, to make a review of the current systems available in the literature and in commercial stores. Secondly, to analyze a sample of applications in order to obtain some conclusions and recommendations. Two reviews have been done: a literature review on Scopus, IEEE Xplore, Web of Knowledge and PubMed and a commercial review on Google play and the App Store. Five applications from each review have been selected to develop an in-depth analysis and to obtain more information about the mobile clinical decision support systems. Ninety-two relevant papers and 192 commercial apps were found. Forty-four papers were focused only on mobile clinical decision support systems. One hundred seventy-one apps were available on Google play and 21 on the App Store. The apps are designed for general medicine and 37 different specialties, with some features common in all of them despite of the different medical fields objective. The number of mobile clinical decision support applications and their inclusion in clinical practices has risen in the last years. However, developers must be careful with their interface or the easiness of use, which can impoverish the experience of the users.

Keywords Mobile applications · Apps · Clinical decision support · mHealth

B. Martínez-Pérez (✉) · I. de la Torre-Díez · M. López-Coronado · B. Sainz-de-Abajo
Department of Signal Theory and Communications, and Telematics Engineering, University of Valladolid, Paseo de Belén, 15., 47011 Valladolid, Spain
e-mail: borja.martinez@uva.es

I. de la Torre-Díez
e-mail: isator@tel.uva.es

M. López-Coronado
e-mail: miglop@tel.uva.es

B. Sainz-de-Abajo
e-mail: beasai@tel.uva.es

M. Robles · J. M. García-Gómez
Biomedical Informatics Group, Instituto de Aplicaciones de las Tecnologías de la Información y de las Comunicaciones Avanzadas (ITACA), Universitat Politècnica de València, Camino de Vera s/n., 46022 Valencia, Spain

M. Robles
e-mail: mrobles@ibime.upv.es

J. M. García-Gómez
e-mail: juanmig@ibime.upv.es

Abbreviations

CDSS	Clinical decision support system
CSW	Clinical standard work
CVD	Cardiovascular disease
eGaIT	Embedded gait analysis using intelligent technology
ESKD	Endstage kidney disease
GOe	Global observatory for eHealth
H&Y	Hoehn & Yahr
IAAP	Imperial antibiotic prescribing policy
IgAN	IgA nephropathy
PD	Parkinson's disease
PDA	Personal digital assistant
PTT	Partial thromboplastin time
QoE	Quality of experience
RFID	Radio-frequency identification
SCORE	Systematic coronary risk evaluation
UPDRS	Unified Parkinson disease rating scale
WHO	World health organization

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Introduction

The creation of the Internet, its extended use and the latest advances in telecommunications and mobile technologies have originated new forms of technology in every aspect of life [1]. One of these aspects is health care, being telemedicine or telehealth the technology most researched, specially the so-called eHealth, defined by the International Telecommunication Union as the paradigm that encompasses all of the information and communication technologies necessary to make the health system work [2]. In this context and thanks to these advances in communications, a new term arises: mHealth, a component of eHealth. The Global Observatory for eHealth (GOe) of the World Health Organization (WHO) defines mHealth or mobile health as "*medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices*" [3].

This mHealth has been supported by the incredibly expansion of the market of smartphones and tablets, thanks to those mentioned advances in mobile and communications technologies such as 3G, 4G, Bluetooth, Zigbee, Radio-frequency Identification (RFID), etc. [4–9]. In numbers, there were in 2011 alone a total of 6 billion mobile subscriptions and more than 1.7 billion mobile phones sold in 2012, being 712.6 million smartphones [10]. Regarding tablets, there are estimated 117.1 and 165.9 million shipments in 2012 and 2013 respectively [11].

This fast spreading of mobile devices has propitiated the creation and growth of the mobile apps market. Focusing only on the most important app stores, in terms of the market share of smartphone operating systems [12, 13], the App Store [14] for Apple iOS has close to 20,000 apps in the category of Health & Fitness and more than 14,000 in Medicine whereas Android's Google play [15] has more than 11,000 apps in the Health & Fitness section and roughly 5,000 in the Medical apps section [16].

The potential for mHealth applications is well-documented [17–20], e.g.: continuous surveillance of vital or physiological signs, move away from face-to-face visits at the doctor's office, access information relative to medications, view your own electronic medical record and access to a wide array of educational resources including information on disease-specific topics and general self-management tools.

Recently, there are proliferating several apps destined for medical professionals and dedicated to support these professionals in the clinical decisions they should make. Although there are many informatics systems usually used in health care facilities and organizations [21–24], the implementation of these systems in mobile devices is relatively new and the advantages it can provide are many: portability, possibility of customization, always at hand, low cost, etc. Hence, these new types of apps for medical decision support can enhance the existing systems in this field, being inseparable tools for physicians, nurses and specialists of health care.

Clinical Decision Support Systems (CDSS) link health observations with health knowledge to influence health choices by clinicians for improved health care. These systems are aligned with the P4 Medicine objectives to personalized diagnoses and treatments, predict the patient status and follow-up based on multi-level observations, generate preventive polices in risk patients and empower patients to actively participate in their health.

High performance CDSS are usually based in two technologies: Rule-Based Systems and Machine Learning models. Rule-Based Systems (RBSs) are computer-based systems that represent knowledge by IF…THEN rules. In CDSS, RBSs implement medical evidence linked to the patient conditions observed in the clinical data. Machine Learning models are mathematical functions to estimate the risk of patients given the observations. They are usually trained from retrospective data from real patients to solve diagnoses, treatments, or prognosis.

The aim of this paper is to study the existing applications for mobile devices dedicated to the medical decision support in order to find the different types of apps in this field, common features, and compare and analyse a representative sample of these apps. To achieve this, a review of the literature about existing mobile systems and applications, as well as mobile apps currently available on the most used app stores has been done.

The remainder of this paper is organized as follows. Next section elaborates about the methods conducted in this study and then there are shown the results obtained. Both sections are separated into three subsections: the first subsection is the literature review of applications and systems, the second is the review of commercial apps and, the third subsection is the analysis of the sample of apps selected. Finally, the last section presents the discussion of the results.

Methods

In this research work, two different reviews were developed. The first was a literature review and the second a commercial applications review. Both were current as of September 2013. Finally, five applications for each review were chosen for an in-depth analysis. The methods used in these reviews and in the analysis mentioned are shown in this section.

Literature review of mobile clinical decision support applications

To perform the literature review, the following systems and databases were used: Scopus, IEEE Xplore, Web of Knowledge, and PubMed. The search was finished in September 2013.

The combination of words used for searching the publications were the following: mobile AND clinical AND decision AND support. The results were limited to the last 7 years, from 2007 forward.

Figure 1 shows a flowchart with the steps followed in both literature and commercial reviews. All the systems and databases returned a total of 405 results, of which 283 were repeated or with an irrelevant title for this study. Out of these papers, 30 were dismissed after reading their abstract or the whole paper when necessary. Finally, a total of 92 papers were selected as relevant.

To include a paper in this study it had to fulfil some criteria: it had to be in English and about one or several mobile clinical decision support applications, although it could include other types of systems or issues. Hence, reviews about the general status of medical systems or applications including decision support systems were included, the same as evaluations about these types of applications.

This process was done by reading the titles and the abstracts of the results obtained in the different databases from one of the authors. When there were doubts about the inclusion of a paper, the whole article was read by all the authors in order to reach an agreement to make a decision.

Review of commercial clinical decision support applications

The review of the commercial applications for supporting clinical decisions was developed in the two applications stores of the most extended smartphone operative systems [12, 13]: Google play for Android [15] and App Store (iTunes) for iOS [14].

The search strings used in both stores were the following: "clinical decision", and "medical decision". The flow chart of Fig. 1 also shows the steps followed in the commercial review. A total of 578 apps were initially found. Three hundred fifty-nine of these apps were repeated, had an irrelevant title or did not have any decision support included, so only 219 were evaluated, of which 27 did not fulfil the rest of the requisites and, therefore, only 192 were included in the study.

The previous requisites were the following: the title and the description of the app had to be in English or in the language of the country where the search was done (Spanish in this case), it had to be included in the categories of Medical or Health & Fitness and be developed for medical professionals of any specialization. Apps developed only for students were dismissed, but those developed for students and medical staff were included in the study. Apps that are guidelines for diagnosis and/or treatment and include some calculators or decisions-tree in order to help the user with the decision making were included in this study. Apps for veterinarians were dismissed.

During the search an issue was faced: on iTunes, apps for iPod and iPhone were separate from the ones for iPad, hence only apps for the first ones were searched since they offer more results, excluding the apps exclusively designed for the tablet of Apple.

This methodology followed was performed by reading the description provided on the corresponding store and, when necessary, the application was downloaded in order to decide its inclusion in the study or not. In these cases, the smartphones used were an iPhone 4 if the app was designed for iOS and a Sony Xperia Z in the case of an Android app. One author classified the apps by their public objective and the field of health care they are destined to. The other two authors checked the classification to be sure there were no mistakes.

Eligibility criteria of the applications for the analysis and procedure

Five papers and five commercial apps were selected for an in-depth analysis of features. The eligibility criteria are similar to the used in a previous work [25].

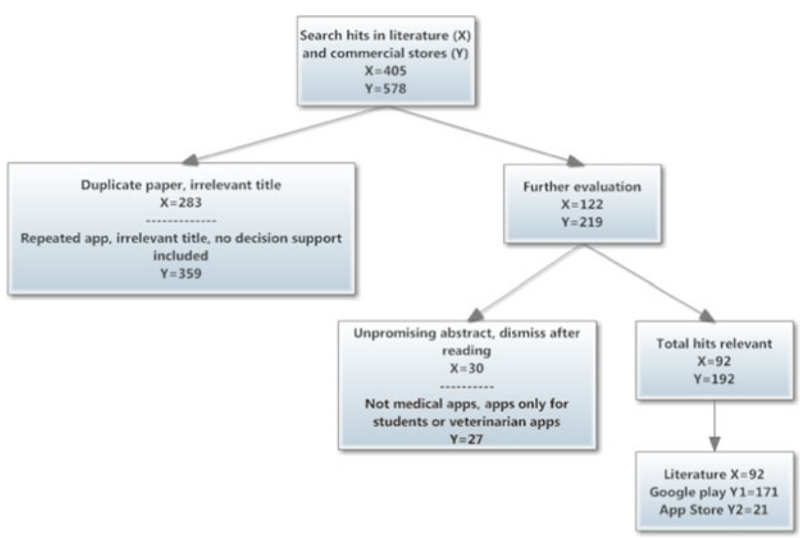


Fig. 1 Flow chart of the steps followed in the reviews

For the mobile clinical decision support systems found in the literature, only the studies published in 2013 were selected. The next requisite for the selection was the highest impact factor of the journal where the paper was published and, if the articles were published in the same journal, the number of citations was taking into account. Articles about reviews of several apps or with insufficient information about the app were dismissed.

To evaluate the papers, each author read them individually and convened to discuss the different opinions they could have until achieve a common agreement about the system or application.

To select the five commercial apps to analyze, it was decided to use the same commercial store and it was chosen Google play, since Android is the most extended smartphones operative system [13]. It was decided to select the five first relevant free apps shown by the store with a rating by users of four or more stars when searching for "clinical decision support". The apps were tested on a Sony Xperia Z.

For the analysis of the applications the procedure followed was similar to the one mentioned with the papers. One author downloaded them on the mentioned mobile phone before meeting with the rest of the authors to study the apps together and complete a table of features.

Results

Mobile clinical decision support applications in literature

A total of 92 relevant papers were found in the systems mentioned previously. Figure 2 shows the distribution of these publications by their year of publication, indicating the number of documents per year. It can be observed an increasing progression in this number of papers with the years.

Regarding to the type of papers found, several were obtained. There are papers about the development of complete and specific mobile decision support systems such as the system developed by Savel et al. (2013), where an iOS-based mobile application called PTT (Partial Thromboplastin Time) Advisor is developed to offer clinicians a resource to quickly select the appropriate follow-up tests to evaluate patients with a prolonged PTT [26]. There are also many papers about the evaluation and analysis of a mobile decision support system; e.g. the evaluation of the application for iOS iDoc [27], carried out by Hardyman et al. (2013) through surveys for trainee doctors [28].

The results and effectiveness of these systems were also studied in papers such as the one written by Lee et al. (2009), where a trial is developed in order to compare the proportion of obesity-related diagnoses in clinical encounters, documented by nurses using a personal digital assistant-based log with and without obesity decision support features [29]. Only 44 papers out of 92 were focused only on mobile CDSS.

Finally, there are two types of papers that include these clinical support systems in a more global way. On one hand there are reviews of these systems, such as the one developed by Divall et al. (2013), where the authors carried out a systematic review of the use of PDAs in clinical environment, including the decision support [30]. On the other hand, other papers simply expose the possibilities and possible contributions that mobile clinical support systems can provide [31].

Commercial mobile clinical decision support apps

A total of 192 commercial apps for supporting the clinical decision were found. One hundred seventy-one from Google play and 21 from the App Store. One hundred thirty-eight results were found using the search keywords "clinical

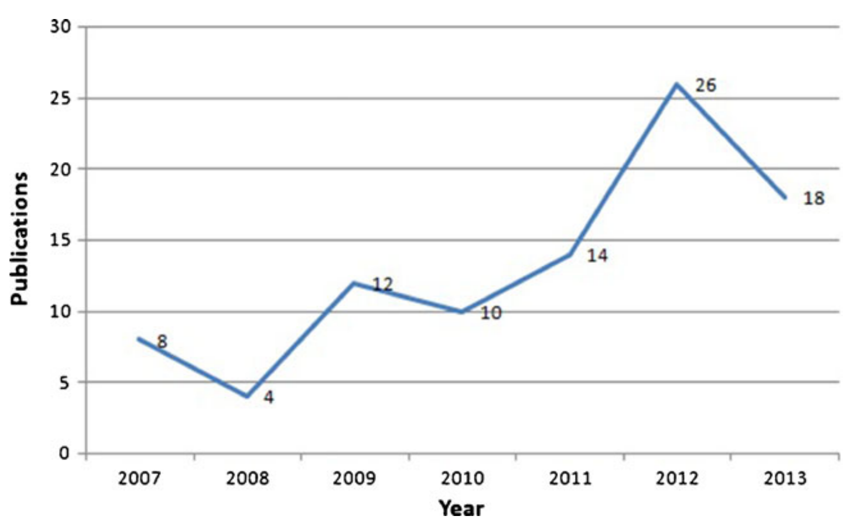


Fig. 2 Number of papers found per year of publication

Table 1 Classification of apps in the commercial review by medical field

Medical field	Number
General medicine	47
Drugs information	16
Emergencies	12
Pediatrics	11
Cardiology	7
Oncology	7
Psychiatry/mental health	7
HIV	6
Infectious diseases	6
Lab values	6
Neurology	6
Cardiovascular	4
Dermatology/wounds	4
Gynecology	4
Hematology	5
Radiation therapy/Radiology	4
Gastroenterology	3
Anesthesia	3
Hepatitis	3
Nutrition	3
Orthopedics	3
Respiratory system	3
Surgery	3
Urology	3
Diabetes	2
Geriatrics	2
Imaging	2
Albuminuria	1
Day time somnolence	1
Dysanatremia	1
Endocrinology	1
Hospital	1
Insomnia	1
Nephrology	1
News/research	1
Ophthalmology	1
Sclerosis	1

decision" and 172 using "medical decision". One hundred eleven apps were obtained using both search strings. Table 1 shows the number of apps sorted by the type of medical field they are intended for. In Fig. 3 the percentage of apps classified by the objective public to whom they are developed is shown.

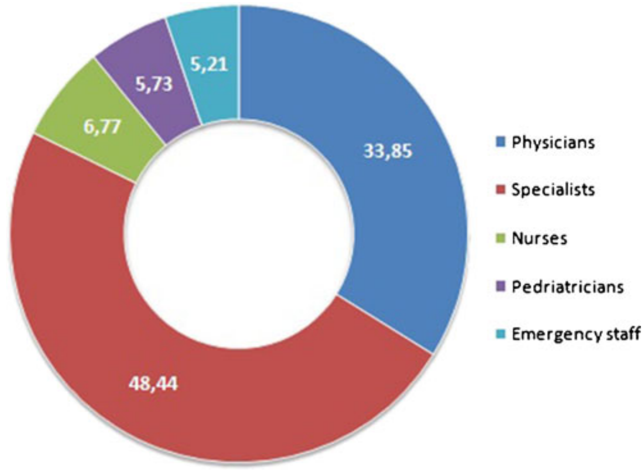


Fig. 3 Percentages of apps by objective users

Analysis of a sample of systems and applications

First we analyze the systems selected from the literature review. These papers are the following: An analysis of the development and implementation of a smartphone application for the delivery of antimicrobial prescribing policy: lessons learnt [32]; Unbiased and Mobile Gait Analysis Detects Motor Impairment in Parkinson's Disease [33]; Mobile Monitoring and Reasoning Methods to Prevent Cardiovascular Diseases [34]; An end stage kidney disease predictor based on an artificial neural networks ensemble [35]; Exploiting causal functional relationships in Bayesian network modelling for personalised healthcare [36].

In [32] the authors talk about the development, adoption and implementation process of a smartphone application for antimicrobial prescribing policy called 'IAPP' (Imperial Antibiotic Prescribing Policy). They designed the app in iterative stages focusing on junior doctors and pharmacists. The app was implemented in five teaching hospitals of West London among junior medical staff. After a period of 12 months some surveys were sent to the participants of the study to obtain feedback. The app has clinical calculators and decision support, is native, initially username and password protected and comprised a mobile evolved version of the policy with additional functionality, including therapeutic drug monitoring and clinical calculators. The most appealing features of the IAPP reported by clinical users were its usability, accessibility at point of care, some clinical decision support features and transportability. 81 % of the participants stated that using the app helped them adhere to the policy.

In [33] the authors developed a mobile gait detector, useful for diagnosing motor impairment in Parkinson's disease (PD) patients. This system is called Embedded Gait Analysis using Intelligent Technology (eGaIT) and consists of accelerometers and gyroscopes attached to shoes, data capture, wireless data transfer, feature extraction, and pattern recognition algorithms that record motion signals during standardized gait and leg function. Since clinical scores such as the Unified Parkinson Disease Rating Scale (UPDRS) or Hoehn&Yahr (H&Y) staging are time-of-assessment dependent, it was necessary to made the system mobile. To measure the efficacy of the system, 42 patients and 39 controls were used, who underwent three specific exercises. eGaIT was able to successfully distinguish PD patients from controls with an overall classification rate of 81 % and was able to classify different H&Y stages, or different levels of motor impairment. eGaIT was proved to be able to complete and confirm the global assessment by a clinician.

[34] is about a system that uses a mobile phone to monitor the blood pressure of a patient and a reasoning engine to calculate the Cardiovascular Disease (CVD) risk applying the SCORE (Systematic Coronary Risk Evaluation) method over the blood pressure values and other clinical factors. The system uses a Bluetooth sensor for obtaining the blood pressure data, which will be used taking into account the clinical data of the patient/user to enable the estimation of CVD risk, supporting clinical decisions. As the system depends on the user actions (i.e., the patient must take the blood pressure himself), the system includes notifications and reminders to facilitate this fact. It is focused on adults over 45 years and it is only valid for European regions. The authors evaluated the system through interviews and user feedback after tested it with 23 users, who reported a high satisfaction level but they gave lower ratings to issues related to the way to input information. In general, the usability of the mobile application obtained a rate of acceptance of 69 %.

The authors of [35] developed a mobile tool for predicting Endstage Kidney Disease (ESKD) in patients with IgA Nephropathy (IgAN) disease, which is the most common primary glomerulonephritis worldwide and a leading cause of ESKD thus requiring renal replacement therapy with dialysis or kidney transplantation. The system uses a large and complete dataset of IgAN patients (587) to provide a valuable predictive tool for clinicians. It uses artificial neural networks since they have been proven to be an excellent tool in terms of predictive power as they have the ability to learn. It is embedded in a decision support system called m-IgAN, composed by a server application and two clients: a mobile application and a Web application. Users have to insert the clinical data of the patient, which are sent to the server which checks their validity and, in case they are valid, it predicts the risk degree and sends a set of information to the client containing the prediction and a summary of the patient's data. The system has proved to be efficient as shows the fact that it is being used at Polyclinic of Bari, Italy.

In [36], the authors argued that Bayesian networks offer appropriate technology for the successful modeling of medical problems, including the personalization of healthcare and proposed ways to represent physiological knowledge as part of engineering principles employed in building clinically practical probabilistic models. These principles have been used in implementing a Bayesian network model for preeclampsia being a part of a mobile home-monitoring system. The system is called eMomCare, implemented for Android, and uses smartphones for predicting possible problems. It collects data from the patient and a blood pressure meter connected, which are sent to a smartphone where the Bayesian model is stored, and returns the results obtained from the data. The results of the evaluation of the system were encouraging and show the potential of exploiting physiological knowledge for personalized decision-support systems.

Referring to the commercial review, the five apps selected for the analysis are the following:

- Pediatric Clinical Pathways [37]. This app accesses to the Clinical Standard Work (CSW) Pathways of the Seattle Children's Hospital, which are a documented standard approach that guides practitioners when providing care to specific patient populations, in this case children. These pathways were developed by committees of experts from different disciplines and are presented in an easy-to-read algorithm format.
- Calculate by QxMD [38]. A medical calculator and decision support tool, with algorithms in several medical specialties to impact diagnosis, treatment or determining prognosis. These tools are developed by a collaboration of clinician experts from diverse backgrounds.
- ACC Pocket Guides [39]. A support tool set from the American College of Cardiology Foundation with material adapted and enhanced for Android devices from the full text version of ACC/AHA Practice Guidelines. It contains several tools and calculators, but they have to be downloaded by the user "manually". Actually, the app solicited to download another app called Skyscape [40], which is the one to be used for the user, with the resources obtained from ACC Pocket Guides.
- NeuroMind [41]. Application for neurosurgery with 24 items of interactive clinical decision support and 113 scores that are relevant for neurosurgical practice. It has even anatomical images for explanation to patients and a safe surgery checklist developed by the WHO. The app is supported for several important associations in the field of neurosurgery.
- 2013 Medical Diagnosis TR [42]. An annual guide to all fields of internal medicine intended to accelerate the clinical decision making delivering at-a-glance summaries of the signs, symptoms, epidemiology, etiology, and treatment options for more than 1,000 diseases and disorders. Although the app is free, it offers to the user a free trial of 1 day, being forced to pay for its use after the trial.

The analysis of features is shown in Table 2 whereas Fig. 4 shows some snapshots of these applications.

Table 2 Analysis of features of the sample of commercial apps selected

	Pediatric Clinical Pathways	Calculate by QxMD	ACC Pocket Guides	NeuroMind	2013 Medical Diagnosis TR
Rating	4.7	4.6	4.0	4.2	4.0
Class	Pediatrics	General medicine	Cardiology	Neurosurgery	Internal medicine
Internet requirement	Yes	No	Only login	No	Both possibilities
Form of decision support	Algorithms, tables	Calculators by steps	Tables, logical trees	Calculators	Text
Data visualization	Text, algorithms	Text, numbers	Text, tables	Text, images	Text, images
Context awareness	No	No	No	No	No
Login	No	Yes	Yes	No	No
Frequency of use	Occasional	Occasional	Occasional	Occasional	Occasional
Interface	Simple	Simple	Complex	Simple	Simple
Public	Pediatricians	Any professional	Cardiologists	Neurologists	Any professional

Discussion

Findings

Several interesting findings can be extracted from the results presented previously, especially from the results obtained from the commercial review. Nevertheless, focusing on the literature review, it can be seen that there have been a significant growth in the number of the researches in mobile clinical decision support systems in the last 2 years, with almost half of the papers found (43/92) being published in these years.

The majority of the papers found are about the design, development and implementation of innovative and new mobile clinical decision support systems and their analysis. However, there are other types of papers less common, those about the effectiveness of these systems, systematic reviews of the ones being used currently and those talking about the possibilities, advantages and contributions the implementation and expansion of these tools can achieve.

In the analysis of the papers selected, we can obtain some findings about the systems that are developed. First of all, almost every mobile application found was intended for research purposes, not being available in commercial stores. All of them used a smartphone (as the only hardware used in some cases or as a part of a more complex system in others), which means that the smartphone is the tool the researches focus in their works. However, the purposes and the medicine fields these systems are intended for are very different, existing, as we could see, systems for predicting ESKD in patients with IgAN disease and others for monitoring the blood pressure of a patient to calculate the CVD risk applying the SCORE method, for example. This fact shows that mobile CDSS can be applied to a wide range of fields of the modern medicine. Furthermore, we have seen that their reliability and acceptance among the medicine professionals are very high.

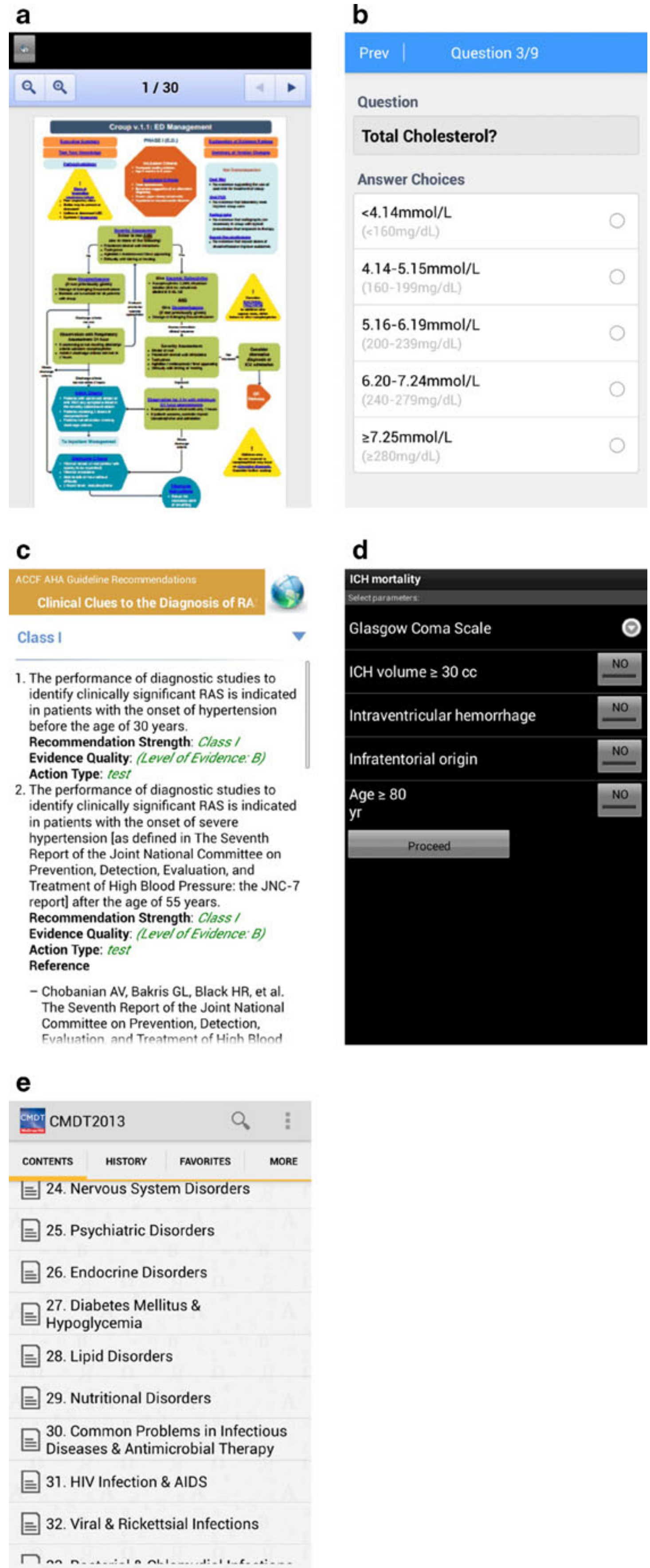
Focusing now on the commercial applications, the first thing that attracts our attention is that it seems that there are many more apps for Android than for iOS, as there were found 171 apps for Android and only 21 for iOS. This difference is explained by the use of different search engines in the commercial stores of Google play and the App Store. In light of the results returned by the same search strings it is clear that the engine of Google play is less strict than the one from the App Store.

The most common medical field of these commercial apps is general medicine, involving all the specific fields of health care. Other fields with many clinical decision support apps are drugs prescribing and contraindications, emergencies services tasks and pediatrics. Cardiology, oncology, psychiatry, neurology and infectious diseases (with special attention to HIV) are among the specialties with more apps. Developers focused their works on these medical specialties since some of the most important causes of death (ischemic heart disease, HIV/AIDS and trachea, bronchus and lung cancers), one of the most prevalent diseases (unipolar depressive disorders), and some of the most disabling diseases (Alzheimer, Parkinson) are included in these specialties [43].

As it can be seen in Fig. 3, almost half of the applications for clinical decision support are developed for medical specialists, such as the mentioned previously. This is logical since, despite the fact that general medicine is the focus of many apps, the majority of them are focused on specialties, as it is shown in Table 1. Excluding specialists and physicians, the rest of the applications are similarly distributed in apps exclusively dedicated for nurses, pediatricians and emergencies staff.

From the analysis of the sample of commercial apps, several similarities and differences can be observed. Although the apps studied are designed for different fields and different types of users, all of them have similar interfaces, being quite simple and based on the use of text. Only one has a more complex interface and it is due to the fact that it is a part of

Fig. 4 Snapshots of **a** Pediatric Clinical Pathways, **b** Calculate by QxMD, **c** ACC Pocket Guides, **d** NeuroMind and **e** 2013 Medical Diagnosis TR



another bigger application. Similarly, all of them do not offer any context awareness such as location, language or user, although some of them require a login. The frequency of use depends on the level of knowledge of the user and the difficuly of the medical issue to cover. Typically, these systems are used for very difficult questions, for training of novel doctors and to review routinary cases semi-automatically.

Among the differences, the Internet requirement is probably the most clear. Some apps need the use of the Internet for showing the information, others only need it for login or doing the first download of information and there are those which are stand-alone applications and do not use the Internet at all. Even there are apps that let the user choose the method to access the information. Referring to the form of showing the decision support tools there are also differences: some use algorithms in form of logical trees, some have calculators which use the data introduced by the user and even only text is used in other apps. These tools also influence the data visualization, which can vary from tables to images, always complementing text.

Recommendations

After checking the existing mobile applications for decision support and trying a sample of them, we have some recommendations to give to the developers of these types of applications. First of all, it is important to avoid using only text for their interfaces. The feeling of these sorts of applications is similar as reading a book. Developers must take advantage of the interactivity the smartphones offer in order to develop a decision support app with more involvement by users. It is useful to use images and logical trees of decision, but we found the best choice the one used in [38], which is using algorithms to assist the diagnosis in several steps. In each step the user has to input some data to finally reach the possible solution. It is also recommended to make clear the steps and the data introduced by the user.

Another aspect to take into account is the time the user requires to interact with the CDSS. In order to reduce it, it is worth to integrate mobile CDSS with EHR or apply incremental forms, in order to reduce the manual input of values. This principle should be mandatory to applications focused in routinely medical problems, but optional for difficult problems.

Another recommendation to developers is to develop apps in the medicine fields with less apps of this type, such as endocrinology, nephrology or ophthalmology, or even focus on common diseases with difficult diagnosis. This way, more specialists and physicians can take advantage of the use of these systems and developers can cover an unexplored field in this type of applications, resulting very profitable.

Conclusions and future work

The number of mHealth apps with CDSS functionalities has been speedily increased during the last 2 years. Several research lines for different medical specialties are opened and many commercial apps for mobile decision support systems are available. Besides, it seems that the research has been increasing in the last years, proving the good reception and acceptance that these systems have obtained from the medical world.

However, there are many applications released focused only on the information contained but not on the interface or the easiness of use and search by the users, which impoverish the experience and, therefore, the valuation from them.

For future work several things can be done. A mobile app for clinical decision support can be developed, focusing on a medicine field with little research and following the recommendations exposed previously. Another line of work can be the evaluation of the Quality of Experience (QoE) from the users of some of these applications using the tools obtained in [44] to write a document with the main steps to be followed by the developers of these types of systems. The purpose of the document would be the design of high quality applications, meeting the users' expectations.

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Conflicts of Interest The authors declare that they have no conflict of interest.

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An Ubiquitous App for the Self-management of Heart Diseases. Implementation and Technical Evaluation

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Complete List of Authors:	Martínez-Pérez, Borja; University of Valladolid, Department of Signal Theory and Communications, and Telematics Engineering De La Torre-Díez, Isabel; University of Valladolid, Department of Signal Theory and Communications López-Coronado, Miguel; University of Valladolid, Deparment of Signal Theory and Communications Herreros-González, Jesús; Catholic University of Murcia, Institute of Biomedical Engineering and Health Technology, 2IByTS
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Abstract:	The introduction of mobile devices in health care has facilitated the creation of a new software industry of health care apps for chronic conditions, such as heart diseases. Due to the lack of self-management apps, the authors created one, called Heartkeeper. The process of its creation is divided into three phases. The first one is a market study and the design of the app, the second one is its implementation and the final phase is its verification. The interface created offers an application based on image buttons, hence, easy to use from the first time. The response times of Heartkeeper operations are of the order of milliseconds. The app was successfully tested in 5 devices with different screen sizes (from 3.5 to 10.1 inches), obtaining a good technical evaluation from the users. Heartkeeper has proved to be a good app.

An Ubiquitous App for the Self-management of Heart Diseases.

Implementation and Technical Evaluation

Abstract

The introduction of mobile devices in health care has facilitated the creation of a new software industry of health care apps for chronic conditions, such as heart diseases. Due to the lack of self-management apps, the authors created one, called *Heartkeeper*. The process of its creation is divided into three phases. The first one is a market study and the design of the app, the second one is its implementation and the final phase is its verification. The interface created offers an application based on image buttons, hence, easy to use from the first time. The response times of *Heartkeeper* operations are of the order of milliseconds. The app was successfully tested in 5 devices with different screen sizes (from 3.5 to 10.1 inches), obtaining a good technical evaluation from the users. *Heartkeeper* has proved to be a good app.

Keywords

App, Heartkeeper, heart diseases, mobile application, self-management

Introduction

Non-communicable diseases (NCDs) are the leading cause of death in the world. Of the 56.8 million deaths in 2008, 36 million were caused by NCDs according to a study from the World Health Organization (WHO). Specifically, chronic diseases are quite important part of this group, being cardiovascular diseases (CVDs) the deadliest diseases with 17.3 million victims in 2008, which represent 30% of all deaths worldwide. Additionally, despite the advances in health care, these numbers are estimated to increase to more than 23 million individuals by 2030[1-5].

Among the CVDs, heart conditions and heart diseases have an important weight in the burden of deceases. Particularly fatal is coronary heart disease (or ischemic heart disease), responsible for 7.25 million deaths in 2008, which, in conjunction with other cardiac conditions, such as hypertensive heart disease and inflammatory heart disease, contributes with a significantly high percentage to the global burden of deceases[5-6]. However, not only the deaths caused by a disease are important, but also the disabilities created. Only coronary heart disease caused a total of 62,587 million Disability-Adjusted Life Years (DALYs) in 2008, which give an idea of the huge number of DALYS that heart diseases provoke. These disabilities mean more hospitalizations and more medical interventions, which influence directly the costs of the health care systems, not to mention the economy costs that the lost productivity of the affected causes. Only in the United States, these global costs derived from the heart diseases were estimated at $448 billion in 2008[7-8].

The advent of information technology in health care and the incredible expansion of the market of smartphones and tablets have created a new mobile health applications software industry. These new health apps are continuously increasing: focusing only on the most important apps stores, there are more than 11,000 apps in the category of Health & Fitness and almost 5,000 in Medicine in Android's Google play; and almost 20,000 apps in Health & Fitness section and more than 14,000 in Medicine in Apple's App Store[9]. Focusing only on cardiology, 439 apps for iOS and 271 for Android were found in 2013 in a previous work of the authors[5].

Since heart diseases cause so many deaths and disabilities, it is obvious that there are many health apps focusing on these illnesses. Many of them are designed for patients' use, such as those for monitoring the heart rate in order to detect abnormal rhythms and warn the user[10], others for cardiac rehabilitation[11], some for resuscitation in case of heart infarction[12], and even those for auto-diagnosis[13], among other types. There are also apps for health care professionals, such as those who must continuously monitor the patients[14], those that use mobile phones in order to assist the professional in their decisions[15], or even some who use smartphones for phonocardiography applications to evaluate the cardiovascular function[16]. Summing up, there are many apps in cardiology developed for different objectives and proved to influence positively on chronic diseases in general and heart diseases in particular[2,17-18]. However, the authors identified a lack of apps for self-management of heart diseases and conditions[5], deciding to create one with this purpose, being the aim of this paper to present this app called *Heartkeeper*, showing the outcomes of its design, its development and its verification and acceptance by the users.

Methods and Procedures

The global creation process for *Heartkeeper* can be divided into three phases. In the first phase, the authors discussed and obtained the design issues that the app must perform, such as the functional requirements and the general concept of the app. Once the design is concluded, the second phase, the implementation, can start. This phase was carried out as an iterative process until the app was refined. When a final version was reached, the third phase, the verification, started.

Market Study and Design

Before thinking about the design of the application to be developed, it was essential to research about the existing applications and systems in the cardiology field. This work was finished in July 2013[5] with the following main findings: A total of 710 relevant apps were found in the most important commercial app stores (271 for Google play and 439 for App Store for iOS); The majority of the applications found were designed for general users (affected or not) and health care professionals, being the distribution quite similar: 300 apps for general users (116 in Google play and 184 in the App Store) and 282 for professionals (112 in Google play and 170 in the App Store); The most common apps are heart rate monitors, calculators and predictors, informative guides, apps for assisting the ECG interpretation, apps with news and blood pressure trackers. One of the more striking facts was finding only one app for the heart condition management, aimed only to individuals with heart failure risk.

In light of these results, it was decided to create an app for self-management of heart diseases while at the same time broadening the scope of the diseases assessed: from the few usually tackled by other apps to including the most common of them based on the experience of one of the authors, cardiologist for more than 25 years. These diseases are ischemic heart disease, valvular heart disease, hypertension, and auricular fibrillation. Other important aspects that can influence heart health were included, such as the link between heart and pregnancy, heart and physical activity, and heart and diabetes.

The app is divided into three sections:

- An informative section with medical information that will help the patients to understand their disease, its symptoms and its treatment; and a patient guide in order to inform the users about best practices, prohibitions and life style they should adopt in order to improve their condition.
- A section to record the user's activities (good and bad for their conditions) and health measurements in order to act in consequence with them. Examples of these activities are rehabilitation, physical activity or excesses (in alcohol or food intakes, for example), whereas typical measurements are blood pressure, glucose or cholesterol.
- A section for registering the users' medications and the times when they should be taken, offering the possibility to set reminder alarms. These intakes should be registered in order to create a daily record stored in the calendar.

Implementation

Several operating systems were available for the implementation of the app: Apple iOS, Google Android, Microsoft Windows Phone OS, BlackBerry OS and Symbian. Android was selected as it is the most extended worldwide[19], is open source and, additionally, there are many tools and aid for the development of apps in this platform. Specifically, the tool used for the development of *Heartkeeper* was the Android Software Development Kit (SDK), which includes the Eclipse Integrated Development Environment (IDE) with built-in Android Development Tools (ADT).

Another important issue in the implementation phase was the security and privacy the app must offer, since the data used by the app (personal health data) is very sensitive[20]. This issue was considered very carefully by the authors and they studied the current laws about security and privacy applied to mobile health apps in Europe and the United States in order to fulfil the requirements exposed there. Hence, at the first launch *Heartkeeper* shows a disclaimer and information about the app and the treatment of data it does, along with an e-mail address for contacting the authors.

About the protection of the introduced data, it was decided to implement the data storage in the device itself rather than in a server or in the cloud. This implementation provides important advantages: the data will not circulate through Internet connections, avoiding external attacks typical of wireless links; since the storage is not in the cloud, illegitimate access to the data through Internet is also avoided; the only method to access the data is through the mobile device, so the only way to obtain the information is by stealing the device. In addition to these security motives, there is another more functional, which is the continued access to the app, even when there is no Internet connection available, quite useful for those devices with only Wi-Fi connection or for people who live in rural areas with no 3G coverage[9,21]. Additionally, the most sensitive data of the user was encrypted by a password-based algorithm that uses 256-bit SHA (Secure Hash Algorithm) techniques with random data input that adds additional security, in order to make those data inaccessible in case of losing the device or if it is stolen.

The authors were also especially careful with the implementation of the interface, as it has been proved that the interface design and its user-friendliness is essential in order to attract potential users[9,22]. It has to be simple, intuitive even at first use but also complete, which sometimes can be very difficult to achieve.

The framework of the app is shown in Figure 1. Two layers are shown: on one hand the different modules with their submodules and, on the other, the services and libraries used in each module (or submodule).

Figure 1. Framework of *Heartkeeper*.

Verification

The verification step was divided into two phases. The first was the testing phase, consisting in systematic and exhaustive procedures with *Heartkeeper*, executing all the operations permitted by the app in several devices with different screen sizes. These devices are the following: Samsung Galaxy Mini GT-S6500 (3,5 inches), Samsung Galaxy S SCL GT-I9003 (4 inches), Sony Xperia Z (5 inches), Google Nexus 7 (7 inches) and Samsung Galaxy Tab 3 (10.1 inches). In this phase the response times of the most time-consuming operations of the app were also evaluated in all the mentioned devices in order to verify that *Heartkeeper* is a sufficiently fast app independently of the device used. This is due to the low computational complexity of *Heartkeeper*, with the exception of the encryption / decryption of the personal data stored, which is the most resource-consuming operation. The remainder operations are mainly the generation of the graphics (displays, buttons, lists, texts, calendars, etc.) and the saving/loading data to/from the database, being those the basic operations that the majority of Android apps usually perform.

The second phase is the app evaluation performed by its users. *Heartkeeper* was installed in the mobile devices of 16 common smartphone users in order to use it for one month, some of them with heart diseases, such as a murmur or hypertension. These volunteers were 6 women and 10 man, all of them Caucasian, with an age of 28-40 years old. All of them were contacted by the authors and accepted to participate in the evaluation of *Heartkeeper*. Firstly, they were gathered and the steps of the evaluation were explained to them. Then the authors sent them the .apk file of the app by e-mail in order to be installed in their devices. They used it for a month, and later on, they answered some questions regarding several technical aspects about the application. The questionnaire and feedback collection was don through Google Drive. The questions are shown in Table 1 and the majority of them use the Likert scale being possible the following answers[23]: 1. Strongly disagree, 2. Disagree, 3. Neither agree nor disagree; 4. Agree; 5. Strongly agree. Question 8 is the only one that uses free text.

Table 1. Questions used to evaluate *Heartkeeper*.

Results

Heartkeeper appearance

Heartkeeper has got a main screen that shows several buttons that connects the different sections of the app. A screenshot of this menu is shown in Figure 2a whereas Figure 2b shows a screenshot of the section for storing a medication and its doses. Figure 2c and Figure 2d show screenshots of the calendar of activities and the graphs generated in this case for the registers of pulse, respectively.

Figure 2a. Screenshot of the main page of *Heartkeeper*.

Figure 2b. Screenshot of the creation of a medication register and its doses.

Figure 2c. Screenshot of the calendar of activities.

Figure 2d. Screenshot of the graphs generated for the registers of pulse.

Response times

As mentioned, *Heartkeeper* has been tested in several ways. One of the tests performed was a measure of the response times of the application when executing different actions. This measure is important since the majority of app users do not tolerate launch or waiting times of more than 2 seconds according to a survey from Compuware[22]. Hence, it is totally necessary that the app is launched in less than 2 seconds, and every section is reached almost immediately. Table 2 shows the measure of response times in nanoseconds (ns) when performing different actions. The measures indicated are the mean value of 10 measures for each action.

Table 2. Mean times (ns) of a total of 10 measurements of some operations with *Heartkeeper*.

Users were also asked about their devices and app performance in them in order to verify that the response times remain good in older devices. Answers show that almost every operation was reasonably quick in old devices, except some specific operations, such as the encryption/decryption of the personal data and the drawing of the calendar when many medicines intakes were stored. In this operations, the response times in the oldest devices (LG L3 or Samsung Galaxy mini GT-S5570) were of about 4 or even 5 seconds, which are considered long times. In the case of the encryption/decryption operations, the authors prefer not to change the algorithm because they think that the security is more important than an addition of 2 or 3 seconds to the response time. In the case of the calendar, the authors are currently revising this part trying to improve its performance.

Evaluation of the users

As indicated before, *Heartkeeper* was tested by 16 different users for a period of one month and their opinions were collected through 6 different questions. Some values of the opinions obtained for each question using Likert scale (questions 1 to 5) are shown in Table 3.

Table 3. Statistical values obtained from the opinions of a sample of 16 users.

Discussion and Conclusions

In this paper the process of design, creation, implementation and testing of an app for the self-management of heart conditions have been explained. The essential steps an app developer should always do are the following.

The first step was developing a market research to know the existing apps for cardiology in order to see possible opportunities or deficiencies that can be covered. This is probably the most important step for the creation of a successful app. After this, the following phase is thinking the type of the app, its functions and design. Once the app is totally designed, the next step is its implementation, thinking thoroughly in which operating systems will the app be available (if not have been thought before in the design phase), since this decision is crucial for the success of the app. Is in this phase where the authors should think about security and privacy mechanisms that the app must implement according to the current laws of the countries in which it will be released[20]. Finally, it is very important to test and evaluate the app in order to fix errors and wrong behavior in different devices in order to be sure that the final version released will be totally operative without errors. It is also recommended to make a technical evaluation of the app by a sample group of users in order to obtain their feedback and be able to improve it before the release of the app.

While developing *Heartkeeper*, the authors were especially careful with the appearance of the app, as it can be observed in the screenshots of Figure 2. This is important since users are fond of attractive, intuitive and simple interfaces. The authors tried to reduce explanations and irrelevant texts when possible, obtaining as a result a clear application easy to use at first time based on image buttons.

Focusing on the response times of *Heartkeeper*, it is shown in Table 2 that the launch of the app takes about 2 milliseconds in the worst case (the oldest mobile device), much less than the 2 seconds indicated previously. The most time-consuming operation is the encryption/decryption of the personal data of the user, obtaining 2.2 and 2.3 seconds respectively with the oldest device, being less than 1 second in newer devices. Since these operations are only carried out occasionally, it can be concluded that *Heartkeeper* offers good response times in the majority of devices, which are excellent in the newest ones, taken into account even the encryption/decryption operations. However, in old devices the performance of *Heartkeeper* is not optimum, as the response times of the encryption/decryption operations add up to 5 seconds. Nevertheless, the importance of the users' personal data security trumps a few seconds delay, so the current algorithm was kept.

Finally, analyzing the results of the technical evaluation by a sample of users of *Heartkeeper*, the following conclusions can be obtained: In general, the app is positively valued by the users, always over the mean value (3) in all the questions. However, there are aspects less valued than the rest, such as the intuitiveness of the interface or the attraction of the design. On the other hand, the security and protection that *Heartkeeper* offers are the most valued aspects of the users, as much as its response times and its user-friendliness.

For future work there are several opened lines. It can be possible to improve *Heartkeeper* using the results of the users' evaluation, for example making the interface more intuitive, which was the aspect that obtained the worst evaluation, as mentioned. These improvements can be implemented uploading an update of the app. Other option is to add new services to the app, such as including a function to pair an external heart pulse monitor by Bluetooth in order to obtain data in real time, or including a tool for assessing the risk of suffering a heart disease or condition. These new functions can also be added by an update of *Heartkeeper*. Finally, the authors will perform a medical evaluation of the use of *Heartkeeper* in a sample of heart disease patients in order to obtain the improvements that their health can experience with the inclusion and use of the app on daily bases.

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Conflict of interest

No author has a conflict of interest with the contents of this manuscript.

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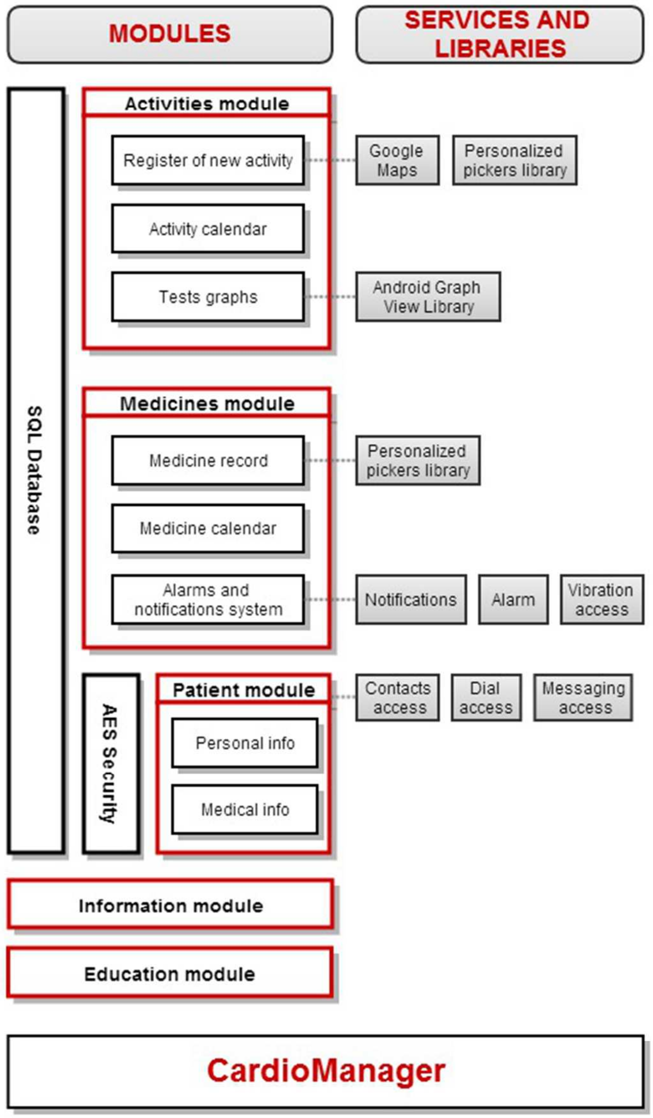

Figure 1. Framework of CardioManager.

Framework of Heartkeeper.
44x74mm (300 x 300 DPI)

Figure 2a. Screenshot of the main page of Heartkeeper.

Screenshot of the main page of Heartkeeper.
211x348mm (96 x 96 DPI)

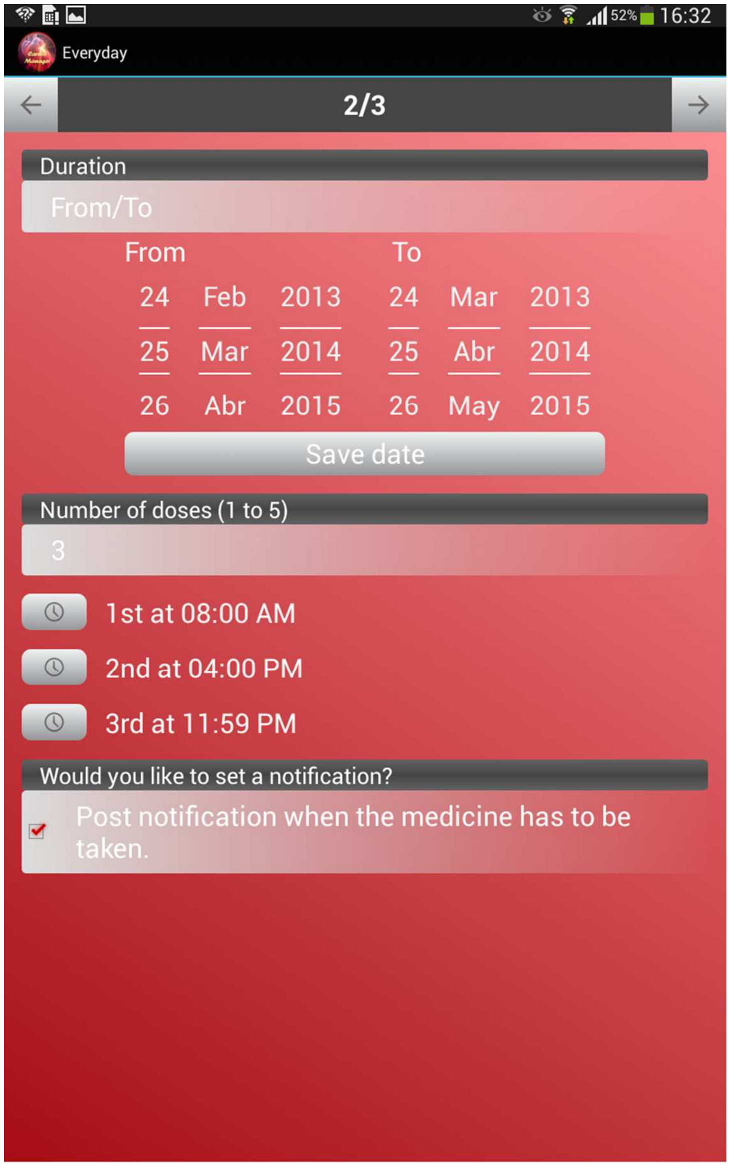

Figure 2b. Screenshot of the creation of a medication register and its doses.

Screenshot of the creation of a medication register and its doses.
67x112mm (300 x 300 DPI)

Figure 2c. Screenshot of the calendar of activities.

Screenshot of the calendar of activities.
67x112mm (300 x 300 DPI)

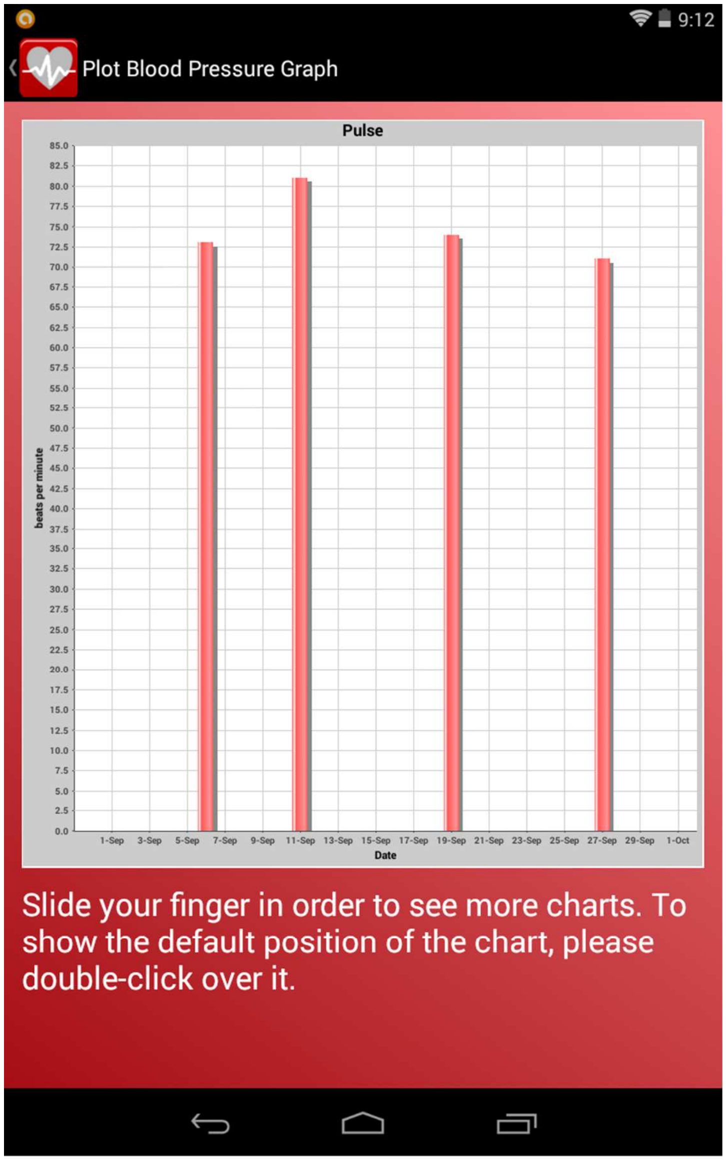

Figure 2d. Screenshot of the graphs generated for the registers of pulse.

Screenshot of the graphs generated for the registers of pulse.
211x352mm (96 x 96 DPI)

Question	Description
1	Is the design of the app attractive?
2	Is the interface intuitive?
3	Is the app easy to use?
4	Do you feel that the app protects your security and privacy?
5	Are the response times of the app fast enough?
6	Would you change/improve/delete any aspect of the app?

Table 1. Questions used to evaluate Heartkeeper.

	Samsung GT-S6500	Sony Xperia Z	Samsung Galaxy Tab 3
Launch	211.826.000,24	110.205.078,20	56.673.023,80
Encryption	2.200.953.999,60	788.012.696,50	728.293.863,35
Decryption	2.319.032.666,40	708.050.537,40	650.942.188,80
Activity DB writing	49.139.777,80	100.712.367,34	72,071391,29
Activity DB reading	25.261.667,00	44.937.134,50	6.549.713,25
Medicines DB reading with 9 registers	15.697.500,95	14.175.415,20	10.826.702,42
Blood test graph drawing with 11 registers	122.416.667,26	258.453.369,65	59.414.637,15

Table 2. Mean times (ns) of a total of 10 measurements of some operations with Heartkeeper.

	Minimum value	Average value	Maximum value	Standard deviation
Question 1	3	3.8	5	0,8618916074
Question 2	2	3.46666	5	1,060098827
Question 3	3	4.13333	5	0,6399404734
Question 4	2	4.2	5	1,014185106
Question 5	2	4.13333	5	1,060098827

Table 3. Statistical values obtained from the opinions of a sample of 16 users.

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ORIGINAL PAPER

Development and Evaluation of Tools for Measuring the Quality of Experience (QoE) in mHealth Applications

Borja Martínez-Pérez · Isabel de la Torre-Díez · Sonia Candelas-Plasencia · Miguel López-Coronado

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Abstract The rapid spread of smartphones and tablets in the last years has created a new software industry whose fast growth has propitiated numerous low-quality applications to be revised and improved. The main aim of this paper is to develop a tool to assess the Quality of Experience (QoE) of mobile Health (mHealth) applications in order to improve the quality of the existing apps and the ones to be released. Firstly, a review of the applications of mHealth has been done in order to obtain a general classification. Secondly, the tool for measuring the QoE is developed in the form of a survey with the help of psychologists. Finally, this tool is evaluated using a sample of applications selected with the aid of the classification obtained. A survey with 21 questions using the Likert scale and destined to users has been successfully created, and its evaluation has been positive, resulting in a good method for measuring the QoE of the different features that the applications in the field of health care usually have. The tool created can be very useful for developers in order to assess the quality of their health care apps, indicating their positive aspects and the ones which must be revised and improved, avoiding the releasing of low-quality apps.

Keywords Evaluation · Likert · mHealth · Quality of Experience (QoE) · Survey

B. Martínez-Pérez (✉) · I. de la Torre-Díez · S. Candelas-Plasencia · M. López-Coronado
Department of Signal Theory and Communications, and Telematics Engineering, University of Valladolid, Paseo de Belén, 15, 47011 Valladolid, Spain
e-mail: borja.martinez@uva.es

I. de la Torre-Díez
e-mail: isator@tel.uva.es

S. Candelas-Plasencia
e-mail: scanpla@ribera.tel.uva.es

M. López-Coronado
e-mail: miglop@tel.uva.es

Abbreviations

QoE	Quality of experience
mHealth	Mobile health
MOS	Mean opinion score

Introduction

The most recent advances done in the last years in wireless communications and mobile technologies have propitiated new ways of providing health care [1–3]. Hence, it is even possible to contact the doctor without going to the health care center. This is conceivable thanks to the recently created smartphones and tablets and their incredibly fast spread, especially in developed and developing zones. In numbers, there are more than 6 billion mobile subscriptions and more than 1.7 billion mobile phones sold only in 2012 of which 712.6 million are smartphones [4]. Regarding tablets, there are estimated 117.1 and 165.9 million shipments in 2012 and 2013 respectively [5].

This outstanding distribution of smartphones and tablets has propitiated the creation of a new branch in the industry of software, the development of mobile applications or apps, understood as programs for smartphones and tablets which can be downloaded directly from a commercial store in the device. This new industry has grown rapidly to the point that there are currently more than 800,000 apps in each of the two most important commercial stores [6] in terms of market share [4, 5, 7], which are Google play [8] and Apple iTunes (or App Store) [9].

The problem with the quick growth of this business is that there is a huge number of apps with very low quality in many aspects due to the desire of the developers to be the first in designing and releasing an app to cover a certain unexplored

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field in order to attract the highest number of users possible. In many cases, this results in the releasing of incomplete applications, apps with many errors or apps with important deficiencies for the user's experience. In order to mend this, it seems necessary the use of tools for assessing the quality of the apps before releasing them in the market or even for improving the existing ones. Furthermore, the best practice in this case is to consider the users' feedback or Quality of Experience (QoE), since they are the ones who are going to use and pay the applications. Thus, QoE can be defined as an assessment of the human experience when interacting with technology and business entities in a particular context [10].

The QoE measurement has been used for several aspects: firstly it was created for telecommunication networks [10–12] and then it was incorporated to other ambits such as health care [13] and mobile systems [14] and applications [15]. The aim of this paper is to develop a tool to assess the QoE of mHealth applications in general, based on the previous studies. To achieve this, a general review of mHealth applications has been carried out in order to achieve a classification and, this way, be prepared for the design of a tool for obtaining the QoE. Additionally, this tool has been used with a sample of mHealth apps and the collaboration of patients and health care staff. As a result, we obtained the evaluation of the different characteristics representative of medical apps, which can be very valuable for developers.

The remainder of this paper is organized as follows. Next section elaborates about the methods conducted in this work and later the results of the study are shown. Both sections are separated into three subsections: in the first the classification of mHealth applications obtained is shown, the second shows the tools obtained for assessing the QoE, and the third subsection shows the results of their evaluation with a sample of apps. Lastly, the last section presents the discussion of the results.

Methods

As it is said before, the methods followed can be divided into three parts, reflecting the procedures used in each part of the study. In the first part, a research to determine the types of mHealth applications was conducted in order to get a classification. The second part is about the development of the tools to assess the QoE of the apps. Finally, in the third part, these tools are used with a certain number of apps in order to evaluate them.

Classification of mHealth apps

For the evaluation and classification of the existing mHealth applications, three reviews have been done. This way, a review of applications for research has been carried out in the following systems and databases: IEEE Xplore, Scopus, PubMed and Web of Knowledge; aimed to find general mHealth applications and systems. A review of commercial applications was also developed. For this study, some commercial app stores were visited: Google play [8], Apple iTunes [9] (or App Store) and BlackBerry World [16]. Finally, a search on Google of open source applications was carried out.

With the data collected from these reviews, the authors convened to make a classification of the mHealth applications trying to make it in the most general way possible.

Development of the QoE tools

For the development of the QoE tools it was decided to measure the QoE using the metric Mean Opinion Score (MOS), traditionally used in telephone networks to obtain the human user's view of the quality of the network. In this case, it will be used as a subjective measure that quantifies the perceptual effect of different forms of degradation of the service from the point of view of the end-users [17, 18].

Table 1 Applications selected for the evaluation of the QoE tool

Aim public	Type of application	Name of the application
Patients	Treatment of diseases	mobiCeliac (Scanner) [19]
		Meds On Time [20]
		SCORE Cardio Test [21]
	Health awareness	Hearing tests [22]
		Instant Heart Rate [23]
		Accupedo Pedometer [24]
	Content diffusion	Reanimación Cardiorespiratoria [25]
		Doctoralia [26]
		Prospectos [27]
Health care professionals	Aid for professionals	DAS28 - Rheumatoid arthritis [28]
		Anesthesiologist [29]
		Valores de laboratorio [30]
		MedCalc 3000 [31]

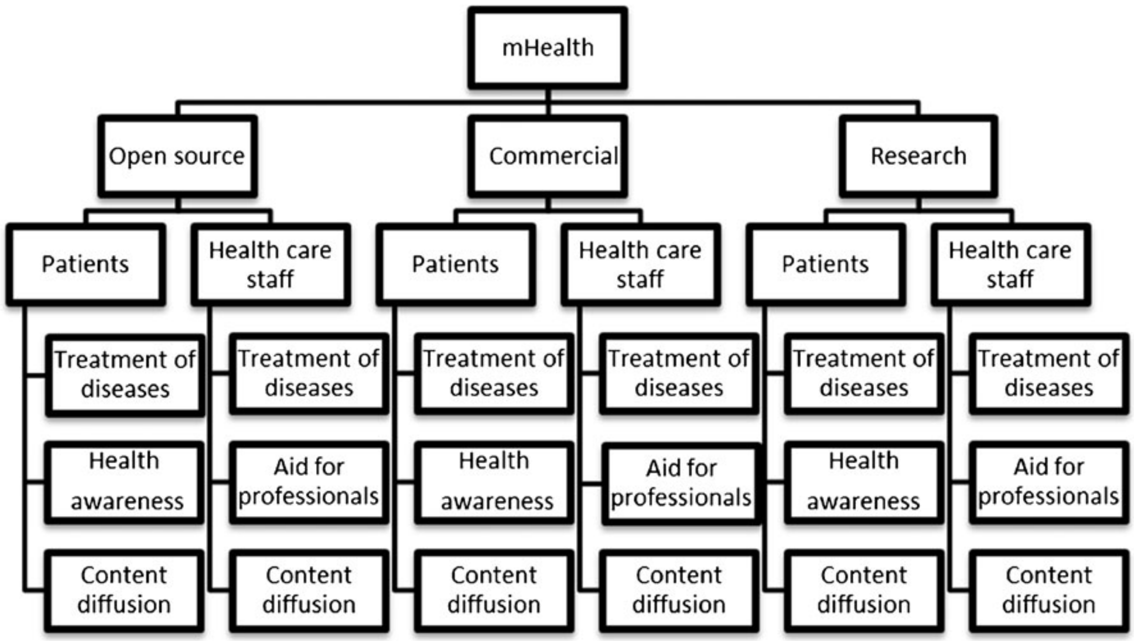

Fig. 1 Diagram with a general classification of the mHealth applications

Table 2 Survey to measure QoE

Content quality		
1	Does it make the function that you expected?	1 2 3 4 5
2	Can you do the same without the application?	1 2 3 4 5
3	Does the application receive updates regularly?	1 2 3 4 5
4	Do you think the data are reliable?	1 2 3 4 5
5	Can you identify with this application health problems?	1 2 3 4 5
6	Do you have possibility to send information about your status to your doctor?	1 2 3 4 5
7	Do you have better quality of life by using this application?	1 2 3 4 5
Security		
10	Do you think that this application has appropriate security methods to protect data that are introduced?	1 2 3 4 5
11	Do you think that the data obtained with this application are sufficiently protected?	1 2 3 4 5
Ease of use		
12	Do you find what you need?	1 2 3 4 5
13	Do you think that the traditional method used so far is more difficult or does not exist?	1 2 3 4 5
14	Is this application useful for monitoring the disease?	1 2 3 4 5
Availability		
15	Do you have the guarantee of access to the application and its data at any time?	1 2 3 4 5
Performance		
16	Do you think you might have a more optimized performance?	1 2 3 4 5
17	Do you find some kind of error or problem while using the application?	1 2 3 4 5
Appearance		
18	Do you find adequate the appearance of this application?	1 2 3 4 5
19	Would you change or add something from this application?	1 2 3 4 5
Learning		
20	Do you think that the time for learning the use of the application is appropriate?	1 2 3 4 5
Precision		
21	Do you think the calculations done by this application are correct?	1 2 3 4 5

Table 3 Survey to measure QoE of not finished applications (research)

Content quality		
1	Would you use the app if developed?	1 2 3 4 5
2	Do you think that in the future it can be useful to society?	1 2 3 4 5
3	Do you think it will improve the quality of life of the users?	1 2 3 4 5
4	Will this future application help in treating diseases?	1 2 3 4 5

The features of the applications that are measured are the following:

- Content quality: users' perception of the quality of the content offered by the mobile application.
- Security: Data security level that the mobile application provides.
- Use: Determines the difficulty of managing the application by the user.
- Availability: Guarantee of access to the information at any time.
- Performance: Errors, unexpected stops of running, response time of the application.
- Appearance: Describes the general look of the product. It is important to state that it is not the detailed design of the interface, only the purpose of the external interface of the application.
- Learning: Specifies the ease to learn how to use the application.
- Accuracy: Quantifies the accuracy of the calculations of the application.

The method for performing the QoE measurement consists in surveys that cover the previous aspects, to be filled in by the professionals or patients in order to obtain the evaluation. These surveys have been developed with the collaboration and advice of psychologists.

Evaluation of the QoE tools

Once finished the surveys for the QoE measurement, the next step was to examine them with several mobile apps in order to evaluate their usability. For this purpose, it was decided to use apps from the same category of the classification settled; hence the commercial category was chosen, since it is the field where the use of these tools can provide the best results. We also decided to use the most used commercial store [7], which is Google play.

For the selection of the apps, we decided to choose a representative sample of them, typical of the subcategories of the classification obtained. We focused on apps for patients, selecting 3 for each subcategory, but we also wanted to evaluate a group of apps for health care professionals. In addition to this, it was also considered in this selection the number of downloads and the rating of the users. The sample of apps used for the evaluation of the QoE surveys is shown in Table 1.

To conduct the evaluation using the developed tool, collaborations of patients and medical staff were needed. In fact, a total of 28 doctors and 112 patients collaborated filling in the surveys provided.

Once finished the evaluations, the results of the surveys were introduced in a powerful program for statistical calculation, IBM SPSS Statistics [32], in order to obtain the statistical results of all the surveys.

Results

This section consists of three subsections corresponding to the subdivisions of the Methods section. In the first part, the classification obtained for the mHealth applications is shown; in the second, the tools of QoE are presented; and the last part shows the statistical results obtained for the sample of apps selected in the evaluation of the QoE tool developed.

Table 4 Results of QoE in the categories of patients and treatment of diseases

Treatment of diseases (Patients)	mobiCeliac (Scanner)		Meds On Time		SCORE Cardio Test	
	Average	Deviation	Average	Deviation	Average	Deviation
Content	2.9429	0.3996	3.2571	0.3857	3.2143	0.2357
Security	4.2	0.7528	3.65	1.0814	4.5	0.5271
Use	3.7	0.6564	4	0.56656	3.7667	0.58899
Availability	3.9	1.1005	4.8	0.4216	4.2	0.63246
Performance	3.3	0.97753	3.5	0.70711	2.95	1.09163
Appearance	3.85	0.62583	3.6	0.5164	4.05	0.55025
Learning	4.3	0.82327	4.6	0.69921	4.8	0.42164
Precision	3.7	1.56702	4.4	0.84327	3.7	1.05935

Table 5 Results of QoE in the categories of patients and health awareness

Health awareness (Patients)	Hearing tests		Instant Heart Rate		Accupedo Pedometer	
	Average	Deviation	Average	Deviation	Average	Deviation
Content	3.7	0.82865	3.4	0.4619	3.04	0.4695
Security	4.5	0.5271	4.2	0.4216	4.4	0.8097
Use	3.9667	0.83813	2.6	0.4389	3.93	0.4661
Availability	4.5	0.52705	4.3	0.4805	4.4	0.5164
Performance	2.8	1.3581	3.98	0.59861	2.5	0.97183
Appearance	3	0.4714	3.65	0.52967	3.4	0.39441
Learning	4.8	0.42164	4.5	0.70711	4.7	0.48305
Precision	3.2	1.13529	3.5	0.70711	4.3	0.82327

Classification of mHealth apps

Figure 1 shows the classification obtained for the different types of mHealth applications. It was decided to divide this diagram in these categories because, after analyzing the existing offer of applications, we thought it was the most optimal way to classify all of them.

Development of the QoE tools

The QoE is a measure from end to end of the functioning of the application, carried out in the service layer and from the perspective of the user, which indicates the degree that the application meets the needs of the user [17].

Table 2 shows the survey designed for measure the QoE of mHealth applications. The way of evaluation is carried out through the Likert scale: 1. Strongly disagree; 2. Disagree; 3. Neither agree nor disagree; 4. Agree; 5. Strongly agree [33].

In the case of applications not finished, such as applications for research under development, the survey centers only on content quality, being in this case as Table 3 shows.

Evaluation of the QoE tools

The results of the application of the survey in the different categories are shown in Tables 4, 5, 6 and 7. Figure 2 shows snapshots of two of the applications used for the evaluation, SCORE Cardio Test and Doctoralia.

Discussion

Some interesting conclusions can be obtained from the analysis of the results, especially those extracted from the evaluation of the QoE for the apps selected.

The classification obtained is a general one with three levels of categories. The first level consists in the types of applications by their objective sectors, their purpose, if they are commercial, open source or research applications. The second level is formed by the types of applications according to their aim public, which can be patients or health care professionals. Finally, the third level is related to the types of applications categorized by their function. Except the block of

Table 6 Results of QoE in the categories of patients and content diffusion

Content diffusion (Patients)	Reanimación Cardiorespiratoria		Doctoralia		Prospectos	
	Average	Deviation	Average	Deviation	Average	Deviation
Content	3.3333	0.4779	3.3	0.3752	3.5	0.4907
Security	4.75	0.5401	3.9	1.1005	4.5	0.8498
Use	3.7333	0.87206	3.4	0.9532	3.8	0.773
Availability	4.6	0.5164	3.2	1.8135	4.1	1.1972
Performance	2.55	0.72457	3.25	0.63465	2	0.94281
Appearance	3.6	0.5164	3.3	0.58689	3.55	0.49721
Learning	4.3	0.82327	3.8	1.39841	4.6	0.5164
Precision	3.7	0.94868	4	0.94281	4.3	1.05935

Table 7 Results of QoE in the category of health care staff and aid for professionals

Aid for professionals	DAS28 – Rheumatoid arthritis		Anesthesiologist		Valores de laboratorio		MedCalc 3000	
	Average	Deviation	Average	Deviation	Average	Deviation	Average	Deviation
Content	3.6	0.2108	3.3167	0.3187	3.7	0.46348	3.7875	0.2286
Security	4	0.5774	4.4	0.9661	4.5	0.5271	3.3	0.2582
Use	4.23	0.4172	4.0667	0.1406	4.4667	0.35832	4.325	0.4257
Availability	4	0	4	0	4.6	0.5164	4.35	0.5798
Performance	3	0.4714	3.1667	0.36004	2.5333	0.28109	2.5333	0.17213
Appearance	2.95	0.36893	3.3	0.48305	3.15	0.33747	3	0.3333
Learning	4.7	0.4805	4.7	0.48305	4.7	0.48305	4.5	0.52705
Precision	4	0	4.2333	0.16102	3.9	0.22498	4.1667	0.17568

the third level Health awareness and Aid for professionals, the rest of the blocks are interchangeable among the 3 levels. Thus, for example, an application for treatment of diseases can be designed for patients with a commercial purpose; or can be designed for professionals in a research environment. This fact shows the generality achieved with these 3 categories used in the classification.

Focusing on the QoE tools, the method of surveys was the one selected because it is well-known, rather extended, useful and with an easy execution, as happens with the Likert scale, used in numerous tests. The main difficulty presented in the development of the surveys was obtaining the questions to cover every aspect of an application without creating too extended surveys for the users, who can get tired or bored and, consequently, fill in the survey incorrectly. Hence, we tried to minimize the questions per feature of the app, trying always to cover the whole aspect. As a result, a total of 21 questions were obtained, achieving a survey with a normal time of completion of 1–2 min, short enough not to annoy the users. Another reason for using the Likert scale is the possibility it offers for introducing the data obtained in statistical programs in order to obtain numerical results suitable to be treated in a statistical way, as it is shown in Tables 4, 5, 6 and 7.

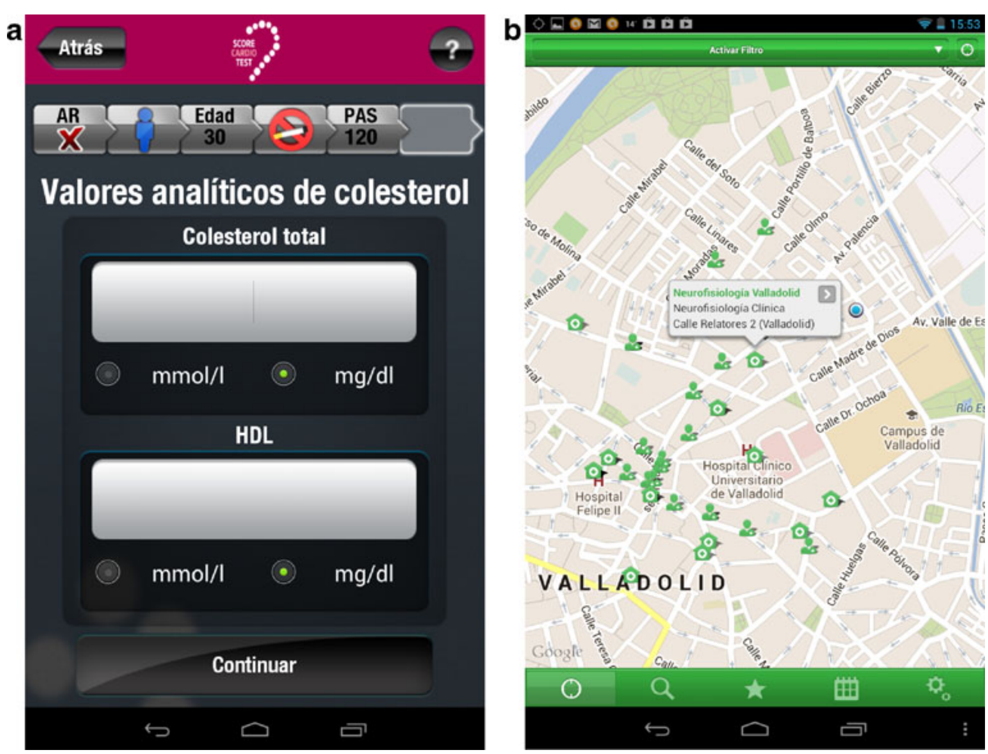

Fig. 2 Snapshots of (**a**) SCORE Cardio Test and (**b**) Doctoralia

We now focus on the analysis and discussion of the results obtained in the evaluation of the survey developed (part 3 of the Results section). As it can be seen in Tables 4, 5, 6 and 7, the results found for all the applications studied are similar excepting some particularities inherent to the apps, what means that the designed tool obtains trusty and reliable results in order to measure the QoE. In addition to this, the users were asked regarding their opinion of the survey and the majority of them (127 out of 140 users) were positive about it. Thus, we have confirmed that the survey can be used for assessing the QoE.

Despite the fact that there are not enough data to establish valuable hypothesis in the general experience of the users in relation to the different categories of the classification done, we will try to venture some suppositions related to mHealth applications. Examining the results, it is simple to see that the best valued requirements are learning and security whereas the worst are contents and performance. This means that developers are more concerned about designing secure apps easy to use than about the correct running and the content of their apps.

It is worthwhile to highlight the case of the content, as it is probably the main reason for a user to download an app and, consequently, the main cause of disappointment if the content is not the expected. Hence, developers must be careful with the description of their apps in the commercial stores, composing it in a detailed and clear way. The performance of an app is another important feature for the feelings of the users. Facts such as large response times, unexpected stops or malfunctions of the app are significant reasons for the user to delete an app forever. As a result, it is essential for developers to debug and check every possible case of running of their apps in order to avoid these errors, which can mean not only the difference between the success or the total failure of the app, but also the failure and discredit of the developer or the company as a whole.

It is appreciated from the results that the apps for health care are very intuitive at first use, important for developers since, if a user needs large periods of time to learn how to use an application, he will probably stop using it and start looking in the store for another app easier to handle. However, this feature of an app does not seem as important as the previous of content or performance since the case of learning is not as critical as the others. The other characteristic with a positive evaluation from the users is the security, what means that the data entered in the application or the data the application generates are not easy to obtain for another person who is not the owner of the app. The causes for this is that the majority of these types of applications generate information that is not stored and, consequently, cannot be found by anyone; moreover, when the app stores this information, in general, they have methods to avoid unauthorized accesses such as user's authentication and data encryption.

For future work several considerations can be taken into account. It is possible to develop a mobile app for a specific aspect of health care and, once finishes, test the QoE of the app with the tool achieved in order to get the necessary feedback to obtain, after the required iterations, a product with a positive evaluation in every aspect. Another possibility is to use the QoE survey with a sample of apps related to a field of health care sufficiently big to get trusty and reliable hypothesis about the most and worst valued characteristics of the apps.

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Conflicts of Interest The authors declare that they have no conflict of interest.

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Experiences and Results of Applying Tools for Assessing the Quality of a mHealth App Named Heartkeeper

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Corresponding Author:	Borja Martínez-Pérez, MSc. University of Valladolid Valladolid, Valladolid SPAIN
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	University of Valladolid
Corresponding Author's Secondary Institution:	
First Author:	Borja Martínez-Pérez, MSc.
First Author Secondary Information:	
Order of Authors:	Borja Martínez-Pérez, MSc.
	Isabel de la Torre-Díez
	Miguel López-Coronado
Order of Authors Secondary Information:	
Abstract:	Currently, many incomplete mobile apps can be found in the commercial stores, apps with bugs or low quality that needs to be seriously improved. The aim of this paper is to use two different tools for assessing the quality of a mHealth app for the self-management of heart diseases by the own patients named Heartkeeper. The first tool measures the compliance with the Android guidelines given by Google and the second measures the users' Quality of Experience (QoE). The results obtained indicated that Heartkeeper follows in many cases the Android guidelines, especially in the structure, and offers a satisfactory QoE for its users, with special mention to aspects such as the learning curve, the availability and the appearance. As a result, Heartkeeper has proved to be a satisfactory app from the point of view of Google and the users. The conclusions obtained are that the type of tools that measure the quality of an app can be very useful for developers in order to find aspects that need improvements before releasing their apps. By doing this, the number of low-quality applications released will decrease dramatically, so these techniques are strongly recommended for all the app developers.

Experiences and Results of Applying Tools for Assessing the Quality of a mHealth App Named Heartkeeper

Borja Martínez-Pérez, Isabel de la Torre-Díez, Miguel López-Coronado

Department of Signal Theory and Communications, and Telematics Engineering.
University of Valladolid
Paseo de Belén, 15. 47011 - Valladolid, Spain
Phone: +34 983423000 Ext.3703;
Fax: +34 983423667
E-mails: borja.martinez@uva.es, isator@tel.uva.es, miglop@tel.uva.es

Corresponding author:

Borja Martínez-Pérez

Department of Signal Theory and Communications, and Telematics Engineering.
University of Valladolid
Paseo de Belén, 15. 47011 Valladolid, Spain
Phone: +34 983423000 Ext.3703
Fax: +34 983423667
Email: borja.martinez@uva.es

Abstract

Currently, many incomplete mobile apps can be found in the commercial stores, apps with bugs or low quality that needs to be seriously improved. The aim of this paper is to use two different tools for assessing the quality of a mHealth app for the self-management of heart diseases by the own patients named Heartkeeper. The first tool measures the compliance with the Android guidelines given by Google and the second measures the users' Quality of Experience (QoE). The results obtained indicated that Heartkeeper follows in many cases the Android guidelines, especially in the structure, and offers a satisfactory QoE for its users, with special mention to aspects such as the learning curve, the availability and the appearance. As a result, Heartkeeper has proved to be a satisfactory app from the point of view of Google and the users. The conclusions obtained are that the type of tools that measure the quality of an app can be very useful for developers in order to find aspects that need improvements before releasing their apps. By doing this, the number of low-quality applications released will decrease dramatically, so these techniques are strongly recommended for all the app developers.

Keywords

Android guidelines; App; Heartkeeper; Quality of Experience (QoE); mobile health (mHealth).

Introduction

In the last years, the world has seen one of the most important changes in the technology field: the boost of mobile devices such as smartphones and tablets and the creation and incredibly quick expansion of the industry of mobile applications. These can be understood as programs for the mentioned mobile devices that can be downloaded in the device by using its commercial store. Currently there are more than 1.5 millions of apps for the two most important commercial stores [1] in terms of market share [2-4], which are Google play [5] and Apple App Store [6].

Some aspects such as the great success of some well-known apps (Angry birds, WhatsApp,), the relatively ease to develop an app, the fact that the development tools are free, and the lack of barriers for releasing an app have propitiated that almost everyone with minimum IT knowledge can develop and release an application [7]. However, there are many apps with poor quality since they are developed by people with not enough software development skills or patience. As a result, these apps can present errors and bugs, be incomplete, improperly designed or with incorrect use of the language [8].

For avoiding the release of these low-quality apps, developers should use mechanisms to test their apps in the production phase, such as measuring response times, trying all the possible actions allowed in the app, or checking its visual aspect, among others.

It is also important to be in line with the usability guidelines proposed for the operating systems where the apps are released. Hence, some guidelines with this purpose are available to developers [9-12]. Very interesting is the guideline proposed by Cruz Zapata et al. [13], obtained from the recommendations to developers made by the own Google (for Android) and Apple (for iOS): Android Design Guidelines [14] and iOS Human Interface Guidelines [15], respectively. They designed a questionnaire with a total of 13 questions in order to obtain information about the style, behavior and structure of the app.

Another important aspect to have in mind is the use of a tool to measure the users' Quality of Experience (QoE). The authors created one of these tools in a previous work [16], specially designed for assessing the QoE of mHealth applications. This tool is a survey that uses the Likert scale (1 to 5) in a number of questions that involves different aspects, such as content quality, security, ease of use, availability, performance, appearance, learning and precision of the mobile app.

The aim of this paper is to apply the methods mentioned to a mobile app designed for Android named Heartkeeper [17], which was developed by the authors for the self-management of heart diseases and conditions by the own patients. Therefore, the surveys developed by Cruz Zapata et al. and Martinez-Pérez et al. in different works will be applied to a real mHealth application in order to evaluate the compliance with the recommendations established by Google for Android apps, in this case, and the users' QoE.

The remainder of this paper is organized as follows. Next section elaborates about the methods used in this study, then the results of the research are shown and, finally, the discussion and conclusions of the results will be presented.

Methods

Description of the app to study

The app to study is named Heartkeeper, and its purpose is to allow heart patients the self-management of their diseases or conditions, assessing the most common, which are ischemic heart disease, valvular heart disease, hypertension, and auricular fibrillation. It also includes other relevant aspects for the heart health such as the relations between heart and pregnancy, heart and physical activity, and heart and diabetes. Heartkeeper was developed with the help of an important Spanish cardiologist and has the following sections:

- A section with medical information about the diseases and the aspects mentioned, and a patient guideline about best practices, recommendations, prohibitions and life style in order to improve their diseases.
- A diary with the user's activities and health measurements that can be relevant to his condition. The purpose is to have a control of their actions.
- A section to record the users' medication and the hours that they should have them. The app allows the creation of alarms to warn them of these hours. The intakes are registered and can be seen in a medication diary shown in a calendar.

Heartkeeper was released in October 2014, it is free and it has currently 409 downloads and a valuation of 4.73/5 with 15 opinions.

Tool for measuring the compliance with Android guidelines

The tool used to measure the compliance with the recommendations given by Google to Android developers is extracted from the work by Cruz Zapata et al. [13] and is based on the layers of web design style, behavior and structure [18]. The tool is presented in Table 1.

Each question is scored as follows:

- 1 point if the answer is positive for more than 70% of use cases of the app.
- ½ point if the answer is positive for 30%-70% of use cases of the app.
- 0 point if the answer is positive for less than 30% of use cases of the app.

The method used for applying this questionnaire to Heartkeeper was the direct response of the authors of this work once the app was finished, who gathered to respond together trying to be as objective as possible.

Table 1 Questionnaire for measuring the compliance with recommendations by Google

Q1. Style	
Q1. 1.	Is the writing style simple and informal and is the second person used to talk to the user?
Q1. 2.	Are pictures used to explain ideas?
Q1. 3.	Are pre-defined icons used for common actions?
Q1. 4.	Does the app adapt to both horizontal and vertical orientations?
Q2. Behavior	
Q2. 1.	Are the user preferences learned over time?
Q2. 2.	Do the elements react to the user's gestures by changing color or illumination?
Q2. 3.	Are there confirming messages showing warning information related to actions that the user needs to consider?
Q2. 4.	Are there acknowledging messages to let users know that the action they have invoked has been completed?
Q2. 5.	Do long tasks show non-stationary activity indicators?
Q3. Structure	
Q3. 1.	Is the app loaded immediately without any splash screen or startup experience?
Q3. 2.	Is the login delayed to allow the user to use a particular functionality first?
Q3. 3.	Are suggested structure patterns used: action/tool bar, tab bar, spinner or navigation drawer?
Q3. 4.	Is the navigation consistent when moving between hierarchical screens?

Tool for measuring the users' QoE

The tool to assess the QoE of Heartkeeper is the one obtained in a previous work of the authors [16] and it is basically a survey that uses Likert scale and covers the aspects of content quality, security, ease of use, availability, performance, appearance and learning of the app. Two questions have not been used since they were not relevant for Heartkeeper. These questions were related to performing regular updates, not included since the objective is not to update until obtain feedback from the users; and the other question is related to the precision of the calculations done by the app, although Heartkeeper does not perform any type of calculation. The final survey used is shown in Table 2.

The methods used to apply this survey are the following: Heartkeeper included a button linked to this survey in a Google form [19], and a paragraph motivating the users to fulfil the survey, so every user would be able to access it. The period available for doing this was from October 2014, when Heartkeeper was released, to February 2015 included, a total of 5 months.

Table 2 Survey for measuring the QoE

CONTENT QUALITY		
1	Does it make the function that you expected?	1 2 3 4 5
2	Can you do the same without the application?	1 2 3 4 5
3	Do you think the data are reliable?	1 2 3 4 5
4	Can you identify with this application health problems?	1 2 3 4 5
5	Do you have possibility to share information about your status to your doctor?	1 2 3 4 5
6	Do you have better quality of life by using this application?	1 2 3 4 5
SECURITY		
7	Do you think that this application has appropriate security methods to protect data that are introduced?	1 2 3 4 5
8	Do you think that the data obtained with this application are sufficiently protected?	1 2 3 4 5
EASE OF USE		
9	Do you find what you need?	1 2 3 4 5
10	Do you think that the traditional method used so far is more difficult or does not exist?	1 2 3 4 5
11	Is this application useful for monitoring the disease?	1 2 3 4 5
AVAILABILITY		
12	Do you have the guarantee of access to the application and its data at any time?	1 2 3 4 5
PERFORMANCE		
13	Do you think you might have a more optimized performance?	1 2 3 4 5
14	Do you find some kind of error or problem while using the application?	1 2 3 4 5
APPEARANCE		
15	Do you find adequate the appearance of this application?	1 2 3 4 5
16	Would you change or add something from this application?	1 2 3 4 5
LEARNING		
17	Do you think that the time for learning the use of the application is appropriate?	1 2 3 4 5

Results

Tool for measuring the compliance with Android guidelines

The results obtained from applying the tool for measuring the compliance of Heartkeeper to Android guidelines are shown in Table 3. Moreover, the average score obtained per block is presented in Figure 1.

Table 3 Results of the tool for measuring the compliance with Android guidelines

Style				**Behavior**					**Structure**			
Q1.	Q1.	Q1.	Q1.	Q2.	Q2.	Q2.	Q2.	Q2.	Q3.	Q3.	Q3.	Q3.
1.	2.	3.	4.	1.	2.	3.	4.	5.	1.	2.	3.	4.
1	0	½	1	0	1	½	1	0	1	1	1	1

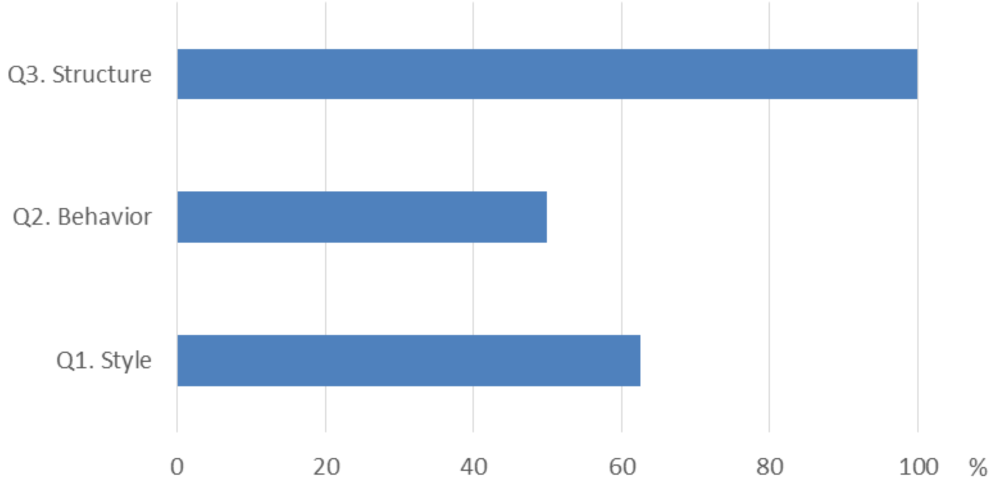

Fig. 1 Average score obtained per block with the tool for measuring the compliance with Android guidelines

Tool for measuring the users' QoE

A total of 24 responses to the survey were collected. Since they are not many, in Table 4 all the responses are shown indicating the number of responses obtained for each possible score.

Table 4 Results of the tool for measuring the users' QoE

	# of 1	# of 2	# of 3	# of 4	# of 5	**AVG**	**ST DEV**
Q1	0	0	6	11	7	**4.04**	**0.73**
Q2	2	6	6	8	2	**3.08**	**1.11**
Q3	0	3	7	7	7	**3.75**	**1.01**
Q4	0	1	7	12	4	**3.79**	**0.76**
Q5	0	1	8	9	6	**3.83**	**0.85**
Q6	0	1	7	14	2	**3.71**	**0.68**
Q7	0	1	10	8	5	**3.71**	**0.84**
Q8	0	1	8	11	4	**3.75**	**0.78**
Q9	0	4	9	8	3	**3.42**	**0.91**
Q10	1	2	7	12	2	**3.50**	**0.91**
Q11	0	2	3	13	6	**3.96**	**0.84**
Q12	0	2	8	7	7	**3.79**	**0.96**
Q13	1	6	6	9	2	**3.21**	**1.04**
Q14	2	0	3	13	6	**3.88**	**1.05**
Q15	0	1	6	11	6	**3.92**	**0.81**
Q16	0	6	2	11	5	**3.63**	**1.07**
Q17	0	0	8	8	8	**4**	**0.82**

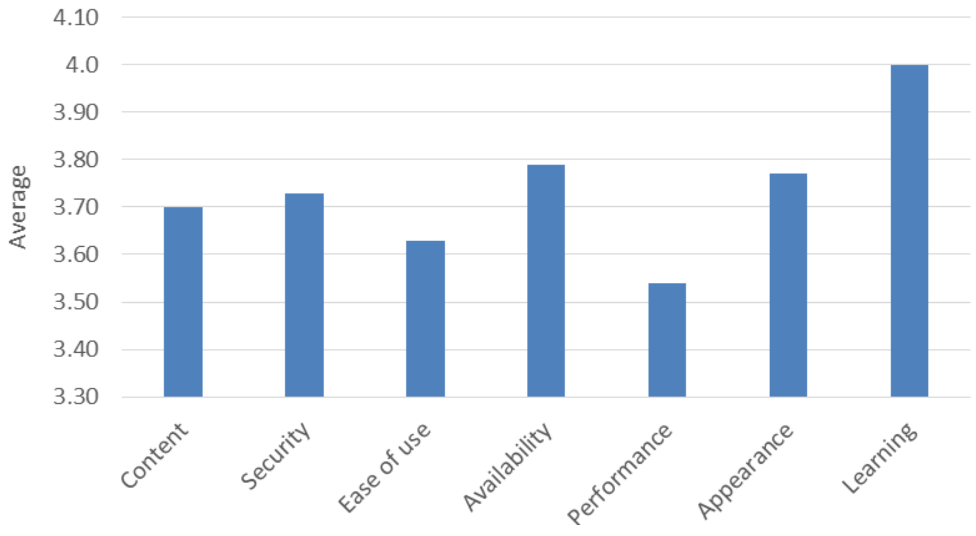

Fig. 2 Score average obtained per block with the tool for measuring the users' QoE

The second to last and the last rows show the average score and the standard deviation respectively for each question. In Figure 2 the score averages obtained for each block of the survey are shown.

Discussion

The results obtained are very interesting in order to know the level of quality of the app studied, Heartkeeper. Focusing on the results found from the tool for the compliance with Android guidelines, Heartkeeper is inside the High Quality Group proposed by Cruz Zapata et al. [13], as can be seen in Table 5, which shows the needed scores obtained from this tool for each quality group. Since Heartkeeper obtained a score of 9, it is included in the High Quality Group as mentioned. This means that Heartkeeper is an app that obeys in many cases the recommendations for Android given by Google.

Table 5 Quality Groups by the score obtained from the tool for measuring the compliance with Android guidelines

Score	Quality Group
12-13	Very High
8.5-11.5	High
5-8	Moderate
1.5-4.5	Low
0-1	Very Low

However, analyzing the scores obtained for the different blocks studied, some differences can be observed. Heartkeeper has a score of 62.5% in Style, only 50% in Behavior and 100% in Structure. These numbers indicate that the work done with the structure of the app is perfect, but some changes and updates are needed with the style used and especially in the behavior of Heartkeeper. Besides, the authors are able to identify the specific aspects that have to be revised and modified thanks to this tool, such as using pictures to explain the information given or using non-stationary activity indicators when long tasks are being performed.

The tool for measuring the users' QoE gives very interesting results about Heartkeeper. Generally, the average scores obtained for each answer are good, all of them over 3, which is an indicator of the satisfactory QoE that Heartkeeper provides to its users. Besides, this tool offers much more information. For example, Q1, Q15 and Q17 are the questions with the best punctuation obtained, which means that Heartkeeper do what is supposed to do as it is indicated in the description of the app in Google Play, its general appearance is nice and adequate and the learning curve of the app is appropriate for the users.

However, there are other aspects less valued, such as Q2, Q9, Q10, and Q13, what means that a number of users can do the same without the app or that there are other traditional methods to do a similar function, many of them find it difficult to locate some sections in the app, and some think that Heartkeeper can have a more optimized performance. This feedback is very valuable for developers since they can work in the less-valued aspects by the users.

Additionally, developers can see a comparison among the different aspects that the tool study. In this case, the learning aspect is the most valued, followed by the availability of the app and the general appearance of the interface. On the other hand, the performance of Heartkeeper is the less valued, followed by the ease of use and the content quality. This last aspect can be directly linked with the lack of pictures to explain the information given, what implies that both tools can complement each other perfectly.

However, there are some limitations in the study. The tool for measuring the compliance with Android guidelines is applied only by the authors of this work, so there is a subjective component in the results. Nevertheless, this component is implied by the own tool and it only can be minimized by obtaining feedback from a high number of people. Additionally, the opinion of the authors was given from the most objective point of view possible.

Another limitation is the small number of responses obtained from the tool for measuring the users' QoE in order to obtain relevant statistical conclusions. It would be much better to have a bigger sample to obtain statistical results, but only 24 users responded in 5 months. Hence, the results presented cannot be considered as final and decisive, but they give an idea of the assessment of the different aspects.

In conclusion, this work has shown that the use of tools for assessing the quality or the QoE of mobile apps are very useful for developers in order to find and improve the aspects that needs enhancements according to the feedback obtained. The authors recommend insistently the use of these type of tools because they can improve globally their apps and the valuation of the users, incrementing the number of downloads and, as a result, the benefits.

For future work, it is planned to upgrade and make new developments in Heartkeeper in order to improve the less valued aspects obtained in the two tools used. Additionally, these tools will be applied again once Heartkeeper is updated in order to measure the impact of the new developments in the users' point of view.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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Abbreviations

IT: Information Technology; m-health: Mobile Health; QoE: Quality of Experience.

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MOBILE SYSTEMS

Privacy and Security in Mobile Health Apps: A Review and Recommendations

Borja Martínez-Pérez · Isabel de la Torre-Díez · Miguel López-Coronado

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Abstract In a world where the industry of mobile applications is continuously expanding and new health care apps and devices are created every day, it is important to take special care of the collection and treatment of users' personal health information. However, the appropriate methods to do this are not usually taken into account by apps designers and insecure applications are released. This paper presents a study of security and privacy in mHealth, focusing on three parts: a study of the existing laws regulating these aspects in the European Union and the United States, a review of the academic literature related to this topic, and a proposal of some recommendations for designers in order to create mobile health applications that satisfy the current security and privacy legislation. This paper will complement other standards and certifications about security and privacy and will suppose a quick guide for apps designers, developers and researchers.

Keywords Apps · Recommendations · Laws · Mobile health (m-health) · Privacy · Security

Abbreviations

AES	Advanced Encryption Standard
BSN	Security and privacy in Body Sensor Network
BYOD	Bring-Your-Own-Device
COPPA	Children's Online Privacy Protection Act
EHR	Electronic Health Records
EU	European Union
FTC	Federal Trade Commission
HIMMS	Healthcare Information and Management Systems Society
HIPAA	Health Insurance Portability and Accountability Act
IMEI	International Mobile Equipment Identity
IT	Information Technology
NCVHS	National Committee for Vital and Health Statistics
PHI	Personal Health Information
PKI	Public Key Infrastructure
RFID	Radio Frequency Identification
RSA	Rivest, Shamir and Adleman
SIM	Subscriber Identity Module
TLS	Transport Layer Security
USA	United States of America
VPN	Virtual Private Network

Introduction

In the last years, the significant advances in telecommunications and informatics have propitiated an incredible boost of mobile communications and wireless networks [1–8], as well as an extensive use and expansion of mobile phones, especially smartphones with new features that use these new networks such as 3G and 4G [9–11] and the combination of technologies such as transistor miniaturization, high quality graphs or compact design [12–15]. Hence, the International Telecommunication Union estimated that currently, there are a nearly 7 billion mobile subscriptions (May 2014) [16] and a

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B. Martínez-Pérez (✉) · I. de la Torre-Díez · M. López-Coronado
Department of Signal Theory and Communications, and Telematics Engineering, University of Valladolid, Paseo de Belén, 15. 47011 Valladolid, Spain
e-mail: borja.martinez@uva.es

I. de la Torre-Díez
e-mail: isator@tel.uva.es

M. López-Coronado
e-mail: miglop@tel.uva.es

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study by Gartner said that global mobile phone reached 1.8 billion units in 2013. From those, close to 1 billion units were smartphones [17], and the numbers are increasing continuously.

The smartphones market created a new software industry: one of apps for smartphones. This industry has expanded exponentially and it is continuously in progress. In fact, there are more than 800,000 apps created only for the two most important smartphone operating systems, Apple iOS and Google Android [18, 19]. One of the different fields that have used these new devices and industry is health care. Only taking into account those mentioned operating systems, the Apple iOS' App Store [20] has more than 31,000 apps related to medicine, health and fitness whereas Android's Google play [21] has more than 16,000 medical and health care apps [22]. All these apps are included in what is known as mHealth or mobile health, defined by the World Health Organization (WHO) as "medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices" [23].

However, in this run to be the first in developing and releasing a new app, some aspects have not been properly considered. Among them, privacy and security have a singular importance, especially in those apps that deal with personal and non-transferrable data, such as health applications that store patients' Electronic Health Records (EHRs) or several data regarding their health status. According to the definitions adopted by the National Committee for Vital and Health Statistics (NCVHS) of the US Department of Health and Human Services,"health information privacy is an individual's right to control the acquisition, uses, or disclosures of his or her identifiable health data. Confidentiality, which is closely related, refers to the obligations of those who receive information to respect the privacy interests of those to whom the data relate. Security is altogether different. It refers to physical, technological, or administrative safeguards or tools used to protect identifiable health data from unwarranted access or disclosure" [24].

In addition, clinicians and patients are adopting mobile technologies faster than providers can protect security and privacy, which is a significant problem. According to a recent survey from Healthcare Information and Management Systems Society (HIMMS) [25], clinician use of mobile technology to collect data at the bedside rose to 45 %, up from 30 % last year, and 93 % of clinicians already use their personal smartphone to access EHR, but only 38 % did so under a formal mobile policy. The reality is that physicians and medicine students are unaware of the privacy and security aspects of the mobile applications that they use in their daily activity, as shows the study performed by Whipple et al. (2012). Such study concludes that some education in these issues is necessary because the knowledge about them is very low [26]. Not only the physicians must know about security, but also the health care organizations that have readily accepted the Bring-Your-Own-Device (BYOD) approach because of the convenience and potential cost savings associated with allowing employees to bring their own devices to work [27, 28].

Besides, in the mHealth field significant work is needed in order to overcome legal and cultural differences over privacy between nations and global regions. In this field two types of devices –medical and telecommunications– are converging, and regulators are struggling to keep up, since there are several governments and international bodies that have realized there is a problem to solve, and have moved to address the challenges of personal security and privacy in the era of smartphones and mobile applications [29].

Although there are some researches talking about privacy and security in mHealth in general [30–32], these papers do not deepen into the complexity and the global problem these aspects involve. In addition, there are few researches regarding privacy and security laws for mobile health [33, 34], but many about specific privacy or security techniques in this field [35–39]. Hence, the aim of this paper is to evaluate the current status of these features and make some guides to be followed by designers when creating an app, to satisfy the needed requisites of privacy and security. For this purpose, the authors will develop firstly a review of security and privacy laws in mHealth in developed countries, focusing on the European Union (EU) and the United States of America (USA) in order to know the main aspects to be taken into account by apps designers. Secondly, it will be developed a systematic review of the existing bibliography about the concerns and issues found over privacy and security in mobile health applications, to see the open research lines. Finally, with the knowledge obtained from the previous reviews, some recommendations regarding privacy and security aspects will be redacted, in order to satisfy the requirements stated by the considered laws.

Materials and methods

In this paper, the authors have focused only on laws of North American and European countries because of the difficulty of covering both American/European and Asian/others countries since, generally, laws from Asian countries are different from American/European (more restrictive) and it is necessary to separate them into different studies. In following works, the authors will cover security and privacy laws of Asian countries such as China or Japan, in order to assist designers to create apps for those zones. Similarly, the authors decided to focus only on the EU and USA, in order to simplify this work, selecting them for being probably the most representative zones of the occidental developed countries and two markets that are the objective of an important number of apps designers.

Another limitation is that this paper has taken into account only legal laws concerning security and privacy in mobile health, not certifications or frameworks, since there are frameworks for organizations (commercial companies, government agencies, non-profits) useful for obtaining specific certifications but written in light of the existing laws, which are the critical aspect to take into account by designers. Besides, in the industry of mobile apps, there are many apps created individually by people with no company or organization, just the person itself, so it may not be necessary getting one of those certifications. This study can also complement the existing standards in security and privacy such as ISO/IEC 27001/2013 about information security management [40], which is considered 'the foundation' by security experts worldwide. However, in this case the authors only focused on mHealth aspects.

Once exposed the limitations of this study, the methods carried out were the following: For the first part of this study, the review of security and privacy laws in mHealth in the EU and USA, the steps followed were identifying these laws and reading them carefully in order to extract the main points of each of them, trying to acknowledge common aspects and main differences. As it is mentioned before, the final objective is to summarize the laws that every apps designer should take into account when designing mHealth applications, at least for these countries. The process of identifying the laws, reading them and extracting the main points were performed by one author. The results were given to another author, who also read the laws, in order to revise the results, completing them if necessary.

The following part of this paper was the literature review of privacy and security aspects used in mobile applications in order to obey the laws. For this, the authors sought for published papers retrieved from the systems IEEE Xplore, Scopus, Web of Knowledge and PubMed, using the following search keywords: privacy AND security AND mobile AND health; privacy AND security AND health AND apps; privacy AND security AND health AND smartphones. All types of papers returned by the search were included in the study: security and privacy in apps, encryption, authentication, secure data transfer techniques, system proposals, privacy reviews, etc. Although the terms security and privacy are completely different, the authors sought for them together for two reasons: the first is that they wanted to focus on the relations between them, and the second is that, this way, the results were limited, simplifying the work. When searching for both terms separately, the results obtained were many more and, therefore, much more difficult to handle.

The only requisites needed to include a paper in the study were the following: only papers published in English were studied, the search was limited to the last 8 years, from 2007 to 2014, and the applications included must have health purposes. Figure 1 shows a flow chart of the papers selection process. Initially the systems returned a total of 570 papers, being 334 repeated. Out of the remaining papers, 67 were dismissed since they did not address the issues of this study, resulting a total of 169 relevant papers.

Since the inclusion/exclusion of papers depends on the subjective opinion of the author who performs the review, being sometimes not easy since the abstract is not clear and it can be misunderstood, we enhanced the assessment process with independent verification, as it was done in other works [41, 42]: one author developed the search of literature papers and the rest inspected the results in order to check possible errors. The authors also made a classification of the papers found following the mentioned method.

Finally, the last part of the study, the creation of privacy and security recommendations for mHealth apps designers, was performed using the results obtained in the previous parts of this research. Known the specific laws that the apps must satisfy and the techniques and technologies used for this aspects of security and privacy, the authors convened to discuss what techniques must at least be used and which of them are the most suitable in order to fulfil the laws studied.

Results

Study of the security and privacy laws in the European Union and the United States of America

The EU has one law regarding security and privacy in mHealth: the EU Data Protection Directive 95/46/EC of 1995 [43]. This is a general directive that sets the principles that the Member States should apply in their laws. Recently, at the beginning of 2012, the EU approved a draft, the General European Data Protection Regulation [44], which will substitute the previous directive in 2016 if it succeeds. There will be no need of implementing this regulation in the laws of the Member States since it will apply generally over all of them.

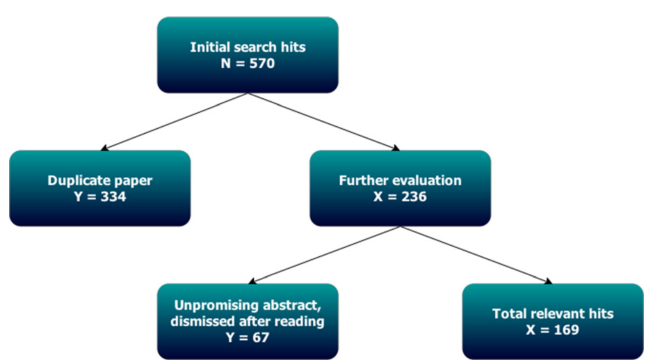

Fig. 1 Flow chart of the steps used in the literature review

With this new regulation all the Member States will be at the same stage of security and data protection.

Contrary at what happens in the EU, USA provides several laws regarding privacy and security in mHealth. The main law that applies to mHealth issues is the Health Insurance Portability and Accountability Act (HIPAA) of 1996 [45]. This law protects the privacy of the digital health information. Another important law is the Federal Trade Commission (FTC) Act [46] with its section 5. This law recently regulated aspects of mHealth privacy in the report "Mobile Privacy Disclosures: Building Trust Through Transparency" [47]. There is another significant law only applicable to children under 13, the Children's Online Privacy Protection Act (COPPA) of 1998 [48], which forbid the gathering of personal information from these children without express consent from a parent or a legal tutor. Finally, there are also State laws, but they will not be considered in this study.

Table 1 gathers a summary of the most restrictive points of the mentioned laws, sorted by the different requirements based on a study performed by Thompsons Reuters [49]. This is, when a law is more restrictive than the others with regard to a specific requirement, Table 1 shows the information of this law. If the laws are very similar regarding a requirement, then Table 1 shows the common aspects extracted from them.

Security and privacy literature review

As mentioned in the Methods section, a total of 169 relevant papers regarding privacy and security in mHealth were found. The classification of these papers by their content is shown in Table 2, which also shows the number of articles for each category in the second column.

As Table 2 shows, there are several research lines found. Below some of the most researched are enumerated, with an example of each line:

- Secure systems or solutions proposal. Sorber et al. (2012) created a wrist-worn device called Amulet that enables a trustworthy and secure path for mHealth devices to communicate with the wearer's mobile phone [50].
- Authentication techniques. Wei et al. (2012) viewed some weaknesses in two authentication methods proposed by other authors and suggested another scheme for telemedicine information systems that solves the weaknesses shown by the others [51].
- Security and privacy aspects in BSNs. In the study of Sahoo (2012), a three tier security architecture for mHealth applications is proposed, using light weight data confidentiality and authentication protocols to preserve the patients' privacy [52].
- General security or privacy aspects. Green (2013) established the necessary steps that healthcare finance leaders must satisfy to develop a good strategy to secure PHI accessed, stored, or transmitted via smartphones or tablets [32].
- Security and privacy in monitoring systems. Shin (2012) designed and evaluated a framework for securing health monitoring systems despite the security flaws of common

Table 1 Laws requisites regarding privacy and security in mHealth applications

Cover data	The data which must be covered are that information that can be used to identify a person. It includes ID numbers, physical, physiological, mental, economic, genetic, social, medical, cultural factors regarding the past, present or future of the patient.
Information requirements	Before providing their Personal Health Information (PHI), users must be informed about the identity of the person/entity that will use the PHI, the purposes of the collecting, the entity's privacy practices, whether the provision is compulsory or voluntary, the rights they have to access/modify the data and a contact method for more information or complaints. This information must be given directly to a parent or legal tutor in case of children under 13.
Consent requirements	The user/patient's consent to the data collecting must be obtained by the entity, when this collecting cannot be justified by a statutory ground. The entity is enhanced to obtain this consent written. In the case of children under 13, they cannot consent their data collection, being their parents or legal tutors the ones to do so.
Data retention	Generally, PHI should be kept only the necessary time for the purpose which was collected and must be erased once the purpose is reached. Entities must also include a clear data retention policy as part of their security procedures.
Security	The entities are required to implement and maintain appropriate technical, administrative, physical and organizational security measures to protect PHI form accidental or unlawful loss and unauthorized access or disclosure. Since health data is very sensitive, the security must be higher.
Breach notification obligations	In case of a personal data breach, the entities must notify it to the competent authority as well as the user whose data has been compromised without unreasonable delay, especially when the breach may have adversely affected to the user. In cases of massive breaches, the media should be also notified.
Data transfers	Entities need the users' consent to transfer their personal data to another entity or a third party, even when this transfer is necessary to complete one of the purposes of the data collecting, unless the transfer is allowed by law.

Table 2 Classification of the results of the literature review

Type of content	# papers
Secure system/solution proposal	23
Authentication technique/system	19
Security and privacy in Body Sensor Networks (BSNs)	11
Security and privacy in cloud computing	11
General security and/or privacy aspects	9
Security and privacy in a monitoring system	9
Security and privacy laws	9
Security in a specific place/context	7
Encryption technique	6
Security and privacy analysis of a system	6
Security and privacy in mHealth emergencies system	6
Security and privacy knowledge evaluation	6
Data transmission privacy and security	5
Security and privacy in Radio Frequency Identification (RFID) systems	5
Security and privacy evaluation of a system	5
Security and privacy in mHealth social networks	5
mHealth security guidelines	4
Security and privacy guidelines for apps	4
BSNs encryption technique	3
BSNs authentication technique	3
Health Information Technology (IT) review	3
Privacy mechanism	3
Security and privacy general aspects in apps	3
Secure data storage technique	2
Location privacy	2

personal devices, building a realistic risk model for sensor-data quality [53].

Security and privacy recommendations in mHealth applications

After reviewing the papers found, the authors were in conditions to make some recommendations to apps designers. Hence, in Table 3 there are shown the requisites that apps designers must satisfy in order to guarantee the security and privacy of the users' PHI. The table is divided into minimum requirements, those that designers must always satisfy; and recommended requirements, those which should be satisfied in order to improve security and privacy.

In addition to the requirements shown in Table 3 it is recommendable to perform periodical audits, preferably executed by external companies, of the security and privacy policy carried out by the entity (the designers). This way, designers can certify that their policies satisfy the legal requisites in privacy and security.

Discussion

Several interesting conclusions can be obtained from the analysis of the results. First of all, in light of the results of the review of the existing laws in privacy and security in mHealth it is clear that there is not a strong line and well-defined statements about this topic, at least in the EU and USA. In addition, the laws were approved long time ago (the EU Data Protection Directive in 1995 and the HIPAA in 1996), when even the term mHealth did not exist. Thus, the statements are based on the obsolete technology of these years and were applicable only in the eHealth field, but currently extended to mHealth. In practice, these laws are too open and too old, and need to be revised and reformulated taking into account the current technologies, industries and health care fields, focusing especially on mHealth and the mobile apps industry, which is continuously expanding. Although this is already happening in some cases (the General European Data Protection Regulation of the EU), the regulations are still too generalist and it seems necessary to create more specific rules mentioning possible technical mechanisms to solve security problems.

Focusing on the results of the literature review, it is easy to see that the most researched fields are those proposing secure systems (generalist or in a specific context or place), or techniques used for security and privacy such as authentication, encryption, data transmission, etc. with special mention to the aspects and techniques of BSNs, very extended lately. These new ideas are very important, but there are other very interesting fields that do not have enough research. For example, there are few security and privacy recommendations or reviews of the existing mechanisms, which is the reason of writing this paper. Location privacy also should be more researched, as the violation of this privacy is not only a violation in health care but also in every general aspect.

Papers about security and privacy in mobile apps deserve special mention, since new health apps are created every day, and they do not usually have enough security and privacy mechanisms in order to protect the users' data, such as lack of privacy policies or users' consent collection [55]. In the literature review, only seven papers focused on apps were found, four with proposed guidelines and three about security and privacy in general terms. It is really interesting the article of Albrecht et al. (2013), which proposes an app-synopsis with some guidelines for designers in order to offer transparent information about their apps, including security and privacy information [56].

Finally, with the information obtained from the literature review, it was possible to write some recommendations for apps designers about the security and privacy methods that they should follow in order to satisfy the laws of the EU and USA. Although taking into account only the minimum requisites exposed is enough for that

Table 3 Security and privacy recommendations for mHealth applications

Property	Minimum requirements	Recommended requirements
Access control	The access control to the PHI must be patient-centric. The users should be able to allow or forbid access to their information at any moment.	It is preferable to create a role-based access, giving reading possibilities to some roles and adding limitations to other ones.
Authentication	The authentication must be done with a unique ID and a password only known by the user. This ID can be linked to a Public Key Infrastructure (PKI), preferable Rivest, Shamir and Adleman (RSA) system and/or a symmetric key used for encryption.	The password used must be complex, with at least seven characters and a combination of letters and numbers, including one capitalized letter and a special character. It is better to employ multifactor authentication to complement the ID/password identification when possible: using an item the user possesses (smart key) or a physical feature such as fingerprint.
Security and confidentiality	Use Advanced Encryption Standard (AES) to encrypt PHI. The cryptographic key used must have at least 128 bits. This method offers better encryption times than other techniques [54].	It is better to improve the security using a key of 192 or 256 bits.
Integrity	At least, a symmetric key-based authentication code must be used, for example AES.	A public key-based digital signature is preferred. Under no circumstances watermarking methods must be used with medical images since they can deteriorate their quality and even provoke bad diagnoses.
Inform patients	Before the collection and use of PHI, the app should present a privacy policy informing the patients about the identity of the entity that will use the data, the purpose of the collection, the privacy methods used, the rights they have and a contact method. If the users accept this policy they give their consent to the data collection. It must include a section for minors, requiring the consent of a legal tutor.	The policy should be easy to understand, concise and clear, since users are not fond of reading large legal documents in an app. It is highly recommended to leave the policy accessible for the user at any moment in the app.
Data transfer	Use Transport Layer Security (TLS) with 128-bit encryption methods. It is also possible to use Virtual Private Networks (VPNs).	It is preferable to use TLS with 256-bit encryption methods. It is also very recommendable to show an icon in the app notifying the transfer of data.
Data retention	The retention policy should be included in the privacy policy to inform the patients. The data should be kept only the necessary time for the initial purpose.	When the purpose is achieved, the PHI must be erased and the user should be notified. The entity should provide a mechanism to let the user check that the data has been deleted.
BANs communication	At least cryptographic methods must be used in securing the BSNs for authentication and key distribution. The mobile device (smartphone) can be identified and authenticated by its International Mobile Equipment Identity (IMEI) or its Subscriber Identity Module (SIM) card number.	The user's biometric patterns user can be utilized to encrypt and decrypt the symmetric key, which can facilitate the connection of the BSNs to the mobile device.
Breach notification	In case of a PHI breach, the competent authority as well as the affected user must be notified as soon as possible (1–3 days). The entity must help the user in order to relieve the consequences the breach may have caused.	It is important to compensate the affected user in order to restore the possible damage done. In cases of breaches affecting a significant number of users, the media must be notified to inform about the problem.

purpose, we strongly recommend the use of the requisites indicated in the third column of Table 3 when possible, since PHI is very sensitive and it must be intensely protected. It is also important to mention that, although we have proposed several technical security mechanisms such as AES, RSA, VPN, etc., there are also other methods equally valid for the same goal. The authors chose those because they are well studied and commonly repeated in the papers reviewed, but the final decisions correspond to the designers.

For future work there are several research lines. It can be a good idea to extend this work by studying the laws regarding privacy and security in other zones, especially in Asian countries, in order to obtain more complete recommendations. Additionally, this work has focused on the security and privacy aspects of mobile health apps, but it does not include other important issues, such as interoperability between different systems. Hence, it can be a good idea to combine both aspects, in order to obtain a secure system but also interoperable, which implies a more complex process and study. Another future line can be the inclusion of the recommendations proposed in a real mobile app in order to evaluate the complexity and the problems that can appear in the process, trying to figure out if the disadvantages of this "extra work" (processing times, higher work load, etc.) can cause that designers opt for not integrating them in their apps, or it is simply lack of awareness of the security and privacy laws.

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Conflicts of interest The authors declare that they have no conflict of interest.

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MOBILE SYSTEMS

Economic Impact Assessment from the Use of a Mobile App for the Self-management of Heart Diseases by Patients with Heart Failure in a Spanish Region

José Antonio Cano Martín · Borja Martínez-Pérez · Isabel de la Torre-Díez · Miguel López-Coronado

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Abstract Currently, cardiovascular diseases are the deadliest diseases with a total of 17 million deaths worldwide. Hence, they are the focus of many mobile applications for smartphones and tablets. This paper will assess the ex-ante economic impact as well as will determine the cost-effectiveness analysis that the use of one of this app, CardioManager, by patients with heart failure will have in a Spanish community, Castile and Leon. For this, a cost-effectiveness analysis using the hidden Markov model were performed in a hypothetical cohort of patients diagnosed with heart failure, based on the information of epidemiological parameters and the costs derived from the management and care of heart failure patients by the Public Health Care System of Castile and Leon. The costs of patient care were estimated from the perspective of the Ministry of Health of Spain using a discount rate of 3 %. Finally, an estimation of the ex-ante impact that would suppose the introduction of CardioManager in the Health Care System is performed. It is concluded that the introduction of CardioManager may generate a 33 % reduction in the cost of management and treatment of the disease. This means that CardioManager may be able to save more than 9,000 € per patient to the local Health Care System of Castile and Leon, which can be translated in a saving of 0.31 % of the total health expenditure of the region.

Keywords App · Cost-effectiveness · Economic assessment · Heart failure · Mobile health (mHealth)

Abbreviations

CVDs	Cardiovascular Diseases
GDP	Gross Domestic Productl
HF	Heart Failure
ICER	Incremental Cost-Effectiveness Ratio
IMF	International Monetary Fund
M-health	Mobile Health
QUALY	Quality-Adjusted Life Year

Introduction

According to the World Health Organization (WHO), more than 25 % of the population has problems related to heart disease. Out of this percentage, 1 % - 10 % is at risk of suffering severe heart failure (HF). Only in Spain there are more than 1,200,000 people with severe HF. There are several causes for HF, being the most important hypertension and ischemic heart disease, especially in developed zones. Out of the 17 million deaths a year that cause cardiovascular diseases (CVDs), complications of hypertension account for 9.4 million deaths worldwide every year. On the other hand, ischemic heart disease is the leading cause of death among CVDs and is responsible for 7.3 million deaths only in 2008. The increasing prevalence of these CVDs is due to population growth, ageing and behavioral risk factors, such as unhealthy diet or sedentary lifestyle [1–6].

From a technological point of view, the fast spreading of smartphones and tablets in the last years has propitiated the

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J. A. Cano Martín · B. Martínez-Pérez (✉) · I. de la Torre-Díez · M. López-Coronado
Department of Signal Theory and Communications, and Telematics Engineering, University of Valladolid Paseo de Belén, 15. 47011 Valladolid, Spain
e-mail: borja.martinez@uva.es

J. A. Cano Martín
e-mail: jcano@sociedadaeronautica.org

I. de la Torre-Díez
e-mail: isator@tel.uva.es

M. López-Coronado
e-mail: miglop@tel.uva.es

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creation of a new software industry: the development of mobile applications (or apps). Currently there are more than 800,000 apps in each of the two most important commercial stores in terms of market share which are Google play and the Apple's App Store [7, 8].

This new industry is included in what is known as mobile health, defined by the WHO as "medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices" [9, 10].

There are many mobile applications developed and researched for treating heart conditions [11–13]. One of these applications is Cardiomanager, a medical app developed by the authors in order to allow heart diseases patients to self-manage their own conditions. It includes the most common of them based on the large experience of renowned cardiologists. These diseases are ischemic heart disease, valvular heart disease, hypertension, cardiorenal syndrome and auricular fibrillation. It was included other important aspects that can influence in the heart health such as the relations between heart and pregnancy, heart and physical activity, and heart and diabetes.

The app is divided into three sections depending on the function carried out. There is an informative section with medical information about the diseases that will help the patients to understand their disease; and a patient guide in order to inform them about best practices, prohibitions and advice they should adopt in order to improve their condition. Another section is used to record the user's activities (which can be good and bad for their conditions) and health measurements in order to act consequently with them. Some examples of these activities are rehabilitation, physical activity or excesses (in food intakes, for example), whereas typical measurements are blood pressure, glucose and cholesterol. There is also a section for registering the users' medications and the hours that they should have them. The app offers the possibility of setting alarms to warn them at those hours.

Since the most important factor for the adoption of information and communication technologies by healthcare professionals is the benefit they would provide [14], the objective of this paper is to develop an economic impact assessment of the use of CardioManager by people with HF, similarly as other studies have done [15–18], which will complement those qualitative analysis of mobile applications already done [19–21]. To reach this objective, the authors developed an ex-ante impact assessment, obtained from the cost-effectiveness analysis of the app and, afterwards, analyzing the impact in terms of saves in the sanitary expenditure that its use by patients and professionals of the Public Health Care System provides.

To do this, given the variety of heart diseases and conditions that constitute the CVDs, it is necessary to limit the analysis to only one specific disease in order to define the pattern of the patient behavior as well as the number of visits to health care professionals, hospitalizations, derivations to other specialists and undergone tests. Hence, ischemic heart disease will be the one selected due to its relevance in causing HF.

Similarly, the key factors that will be necessary to obtain after the analysis are related to costs savings, care quality, monitoring and follow-up of the user/patient, user satisfaction, and the efficiency of the processes of information storage and communication from the app to the hospitals and health care centers.

Besides, it is needed to define the current expenditure in the sanitary system of the region studied, which will be the community of Castile and Leon in Spain, in order to develop an analysis of the savings impact in that system when introducing the app.

Health care expenditure

According to several studies, and if forecasts of economic growth of the economy by the International Monetary Fund (IMF) are correct, no Spanish autonomous community has guaranteed medium-term financial sustainability of its Public Health Care System, understood as the evolution of the dynamics of public health expenditure and government revenue.

The average annual growth of Spanish public health expenditure expected for the period 2013–2016, in the absence of reforms that significantly alter the growth trend observed in previous years, is estimated at 4.4 %, although there is considerable variability between regions [22].

According to the Ministry of Health, Social Policy and Equality of Spain [23] the level of public expenditure in the country in 2011 was nearly 68 million euros. Between 1991 and 2010 public health spending in Spain has grown at an annual rate far from negligible, reaching nominal terms by over 7 % over the period.

Both in terms of Gross Domestic Product (GDP) and per capita spending, there is a remarkable dispersion among autonomous communities. In the first case, the regions with the most expending are those with a lower level of development, because their GDP is lower. However, the dispersion in per capita spending between communities is also important and is maintained even after adjusting spending levels for the different needs relative to population structure (sex and age) of each region.

In the case of the selected region for this study, Castile and Leon, the GDP of 6.5 % of Spain's total GDP and per capita spending of 1,413 € [22]. Also, Table 1 breaks down the health care costs in euros in the main items that comprise it.

In recent years, strategies to improve the quality and sustainability of public health systems are being developed by empowering primary health services, as well as decreasing the spending of specialized and hospital services.

Table 1 Breakdown of public health expenditure by category. Source: Ministry of Health, Social Policy and Equality [23]

	2007	2008	2009	2010	2011
Hospital and specialized services	32.612 €	37.018 €	39.132 €	38.743 €	39.493 €
Primary health care services	9.429 €	10.456 €	10.831 €	10.651 €	10.217 €
Public health care services	839 €	784 €	1.158 €	761 €	750 €
Collective health care services	1.828 €	1.907 €	2.074 €	2.058 €	2.086 €
Pharmacy	11.884 €	12.690 €	13.415 €	13.381 €	12.237 €
Transportation, prosthetics and therapeutic devices	1.081 €	1.230 €	1.298 €	1.351 €	1.332 €
Capex	2.638 €	2.833 €	2.557 €	2.183 €	1.512 €
Total	60.310 €	66.918 €	70.464 €	69.128 €	67.626 €

In the specific field of CVDs, all together account for an average of 17.7 % of total health care expenditure. But specifically HF represents 14.7 % of total health expenditure, which means in a community like Castile and Leon with health costs of 3,332 million euros, almost 490 million euros. Table 2 shows the characterization of HF in Castile and Leon, where there are described the major elements that impact on the cost of health services by HF patients.

Therefore, based on this information, it is relevant to know what would be the impact of introducing the mobile application CardioManager, able to optimize the management of HF patients, in the public health system in Castile and Leon.

Methods

Description of the analysis

For the ex-ante economic impact assessment of the mobile app Cardiomanager a sample similar to the selected by Naveiro-Rilo et al. (2012) will be used [25]. This sample consists of patients with documented chronic HF in the clinical history of primary care, seen through hospital discharge report done by a specialist or by the family doctor physician, and based on Framingham criteria diagnosis and additional tests such as electrocardiogram, chest radiography and echocardiography with characteristic signs of chronic HF. These patients belonged to the sanitary area of Valladolid, which has a population of more than 200,000 individuals over 39 years, of which over 35 % live in the rural area. Patients whose HF was attributable to a reversible cause were excluded.

With the patient records of each physician, an anonymous census was elaborated with 2,000 patients (900 in rural areas), of which a sample was proportionally selected of the urban and rural strata membership to ensure an equal probability of being selected in each stratum, by systematic random sampling. The sample size was calculated to estimate dichotomous variables with an overall accuracy for the health area of 4 % and 95 % confidence, in proportions of 50 %. The result was a size of 630 patients.

To perform the economic impact assessment (ex-ante) [26–29] of the introduction of CardioManager, an economic evaluation type cost-effectiveness [30–32] will be performed on a structured Markov model, using a static deterministic hypothetical cohort with annual cycles and considering the clinical states shown in Fig. 1, composed of a sample of 630 patients diagnosed with HF [25]. In this figure, arrows indicate the possibility of moving to another state. Being an ex-ante assessment we will use a model that simulates the evolution of HF disease, describing the different states that the patient will pass through along his illness.

We considered the cost of the tool worth 100 euros, 90 € for the mobile device with 10 € overhead, whereas the app is free. For health care costs, we used the guide of costs of the Ministry of Health, Social Policy and Equality [33], which imputes direct healthcare costs such as consultations in primary care, emergencies telephone consultation medication, home visits, diagnostic procedures and hospitalization. Non-sanitary direct costs were also included (transport, management overhead etc.). All costs have been adjusted to values in euros for 2011.

At the beginning of the diagnosis of the disease, the patient may have high risk of HF in the future but without structural heart disease in the present (stage A), so that the action is based on a preventive treatment of development of the disease. Likewise, the diagnosis may be on Stage B (structural heart disorders without symptoms of any degree; patients with expulsion fraction of 50 %, normal cardiac output), which also requires a preventive treatment for the detection and treatment of the disease [34–36]. However, when the patient has symptoms of HF in the present or at some point in the past -in the context of a basic structural heart problem and treated medically, cardiac output slightly reduced and Frank-Starling mechanism used as compensation, fatigue or dyspnea with large or moderate exercise present- (stage C), it is required regular treatment and transfer to a primary or specialized health center for monitoring and stabilization. The last stage of the disease (stage D) requires a hospital support, a heart transplant or palliative care (cardiac output slowed, fatigue

Table 2 Characterization of HF in Castile and Leon [24]

	Total	Men	Women	Average stay (days)	
Total deceases	17,089	5,954	11,135	10.03	
Hospitalizations	29,743	16,748	12,995	8.8	
Re-entry rate	Mayor emergency	12		25.08	
	Rest	5,451	1,908	3,543	9.83

and dyspnea at rest) so it is frequent hospitalization for stabilization, destabilization readmissions and high probability of death. Because Markov models [37] assume that state transitions occur at the end of each cycle, a correction has been made assuming that the mean of the cohort transits in the middle of the cycle.

Probabilities considered in the model

Data on HF incidence has been obtained from the Statistics Central of the Ministry of Health, Social Policy and Equality [38, 39]. The remaining transition probabilities introduced into the model in relation to mortality, health care and disease-related events that occur during the year of observation considered are shown in Table 3. The probabilities of death were calculated based on the age-specific mortality rate for 2011 published by the National Statistics Institute [39–41].

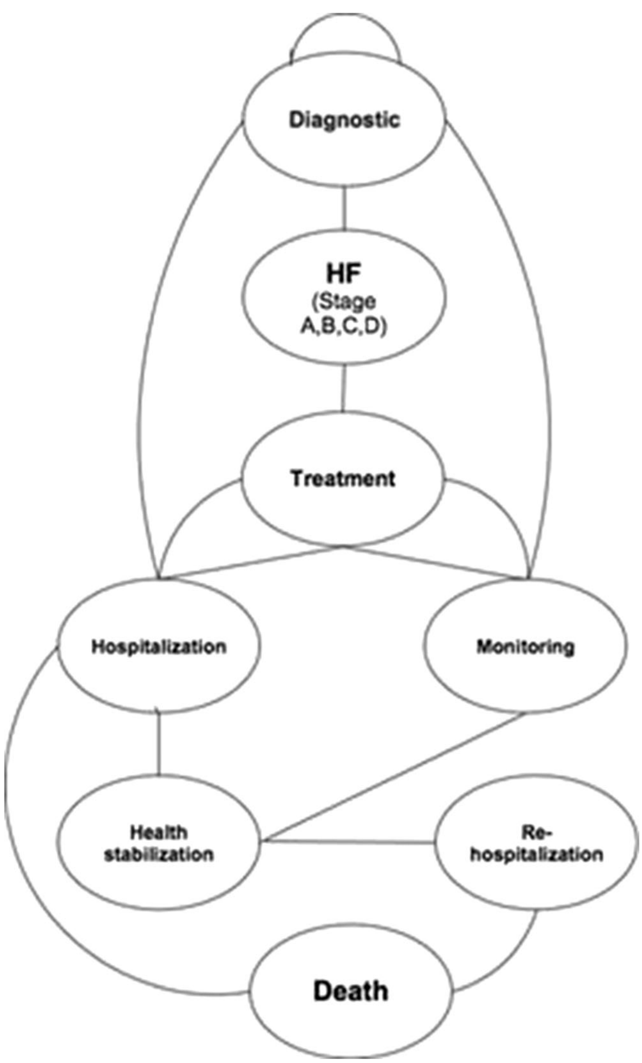

Fig. 1 State diagram of the adapted Markov model

Analysis

The results of the cost-utility analysis have been calculated using the incremental cost-effectiveness ratio (ICER), expressed as cost per additional quality-adjusted life year (QALY) obtained. In addition, a univariate sensitivity analysis has been carried out to assess the robustness of the results when modifying certain variables in a given range (to include the introduction of CardioManager).

The variable efficacy of the introduction of the tool into the sample (introduction of technology efficiency) was analyzed. For the construction and the model analysis the software Tree Age Pro Suite 2009 was used.

Results

Cost analysis

The cost analysis is done from the perspective of the funder of the Health Care System, which, in this case, would be the Ministry of Health, Social Policy and Equality, as these costs are those that has to assume in the process of management and development of the disease: direct costs (direct medical and nonmedical costs such as administration, general services, etc.) [26, 33, 45–47]. Costs are adjusted to the year 2011.

The characterization of the cost of a heart failure patient has been made taking into account the technical paper by the Ministry of Health Care, Social Policy and Equality [48]. Also, to calculate the cost of development and introduction of CardioManager in the public health system in Castile and Leon it is done a projection of which would be to provide each patient with the necessary technology for the management and monitoring of their disease using the application.

The breakdown of costs associated can be seen in Table 4. In the treatment, the cost of drug treatment is excluded, being

Table 3 Transition probability matrix for the Markov model based on [39, 42–44]

	Diagnosis	HF	Treatment	Hospitalization	Monitoring	Health stabilization	Death
Diagnosis	0,9960	–	0,1400	–	–	–	–
HF	–	–	0,9231	–	–	–	–
Treatment	0,9651	0,2079	–	–	0,4765	–	–
Hospitalization	0,4400	0,2795	0,1987	–	–	0,9233	0,1470
Monitoring	–	0,9665	0,6620	–	0,1400	0,034	–
Health stabilization	–		–	–	0,8581	–	–
Death	–	–	–	0,1470	–	–	1,0000

charged only the costs of travel to the health center and the cost per visit.

The introduction of CardioManager in the studied population would generate not only benefits in the health treatment, but also the following savings:

- Testing control in the patient‘s home, saving travels to the hospital or health center for its realization.
- Decrease of the patient displacements derived from decompensations in the patient’s health status.
- Improving the information obtained by the patient, which will mean a better knowledge and control of the disease and, consequently, fewer relapses and hospitalizations.
- Decrease in referrals (from health centers to hospitals, etc.).
- Decrease in hospital admissions due to better health status.

According to [48], the combination of telemedicine and education (main objective of CardioManager) is able to reduce the number of hospitalizations by 60 % and the average stay by 73 %.

Table 5 shows the cost analysis of the two scenarios: without the introduction of the application and with it. It shows that from the perspective of introducing CardioManager, the app achieves greater savings in the management of the disease that would cost without it. Likewise, the ICER obtained measures what it would cost an additional QALY if the application was introduced compared to the scenario of no introduction.

Sensitivity analysis

The effect of the changes in the behavior of patients resulting from the use of the tool on the cost-utility considered in the base case, corresponds to a 33 % reduction in the cost of management and treatment of the disease. This cost reduction would be accompanied by an increase in the efficiency in the management and monitoring of the disease, since higher education combined with tech support [48], substantially improves the patient's response to disease.

Discussion

The most important limitation of the model is attributable to the nature of the target of this paper: perform an ex-ante economic evaluation which would mean to introduce an app like CardioManager on a sample of patients with HF. However, despite not having these data, this lack does not infringe the consistency of the model and the validity of the results, since the analysis was performed following the results obtained in previous studies and reviews of secondary sources. Another important limitation to consider is the perspective of the study, which is the funder. It should take into account the perspective of society, which would allow not only to know what the economic impact (cost savings) of introducing the technology is, but also its social impact.

That said, the results obtained from the ex-ante assessment throw that for the required investment for the implementation of CardioManager of 63,000 € (630 patients x 100 €/patient), a saving of approximately 6 million euros would be generated for the Public Health Care System of Castile and Leon, which can be translated in a saving of 0.31 % of the total health expenditure of Castile and Leon [49].

Namely, the introduction of a mobile application for the control of HF has an impact not only in increasing quality of life and patient autonomy [25, 45, 49], but in turn, provides efficiency to the public health care administration, since it generates savings exceeding 33 % of the total cost of the management of the disease.

This saving will have an impact on both the Health Care System and the economy, since not only there are saves on

Table 4 Analysis of the cost of health states of the established Markov model

States	Unitary cost
Treatment	–
Hospitalization (including health stabilization)	13.889,79€
Outpatient care	1.413€
Re-entry	12.434,4€
Monitoring	577,92

Table 5 Ex-ante global impact analysis of the introduction of CardioManager for the management of HF

States	Without CardioManager	With CardioManager
Hospitalizations (including health stabilization)	13.889€	8.333€
Outpatient care	1.413€	1.413€
Re-entry	12.434€	9.256€
Monitoring and treatment	577	0
TOTAL per patient	28.315€	19.012€
TOTAL sample	17.895.080€	12.015.584€
ICER	–	9.303

costs but there are also gain in efficiency of the system, being able to use the amount remaining for the improvement and sustainability of the future Public Health Care System.

In this case, it would be interesting to carry out an impact assessment using the same sample but giving it the opportunity to use the app so that can be obtained a much more adjusted spending per patient model. Thus, it would be possible to accurately measure not only cost savings, but also quality of life which is achieved by the introduction of the tool. Therefore, the next research line is to test the tool in a sample.

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Conflicts of Interest The authors declare that they have no conflict of interest.

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