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MOBILE SYSTEMS

Mobile PHRs Compliance with Android and iOS Usability Guidelines

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Abstract Mobile Personal Health Records (PHRs) have achieved a particularly strong market share since the appearance of more powerful mobile devices and popular worldwide mobile application markets such as Apple's App Store and Android's Google Play. However, Android and Apple have a set of recommendations on design and usability targeted towards developers who wish to publish apps in their stores: Android Design Guidelines and iOS Human Interface Guidelines. This paper aims to evaluate compliance with these guidelines by assessing the usability recommendations of a set of 24 selected mobile PHR applications. An analysis process based on a well-known Systematic Literature Review (SLR) protocol was used. The results show that the 24 mobile PHR applications studied are not suitably structured. 46 % of these applications do not use any of the recommended patterns, using instead lists or springboards, which are deprecated patterns for top-level menus. 70 % of the PHRs require a registration to be able to test the application when these interactions should be delayed. Our study will help both PHR users to select user-friendly mobile PHRs and PHR providers and developers to identify the good usability practices implemented by the applications with the highest scores.

Keywords mHealth · iOS · Android · Usability · PHR

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Introduction

In 2012 the average smartphone usage increased to 81 % with regard to that of 2011, and the average load of traffic achieved was 342 MB per month and per smartphone, while in 2011 the average was 189 MB [1]. According to the Cisco Global Mobile Data Traffic Forecast 2013 Update [1] the number of mobile devices per capita will have reached 1.4 by 2017. With the expansion of mobile devices, the number of existing mobile applications, from here on termed as apps, is also increasing. In particular, mobile health applications is an emerging market [2,3]. The Mobile Health Market Report 2013–2017 estimates that 500 million people will be using healthcare mobile apps by 2015 [4].

Patients are seeking more usable and portable access to their medical information [5], whereas professionals value the information provided by patients, and even recommend that patients keep these records [6]. This demand has resulted in the development of medical apps that provide electronic access to health information and the growth of mobile personal health record (PHR) apps [4]. Personal health records are health applications that allow individuals to access, manage and share their health information [7,8]. Smartphones and tablets have appeared as the new potential platforms for PHRs [5]. In the Apple App Store alone, there are around 20,000 apps classified in the medical category [9]. The medical practice supported by mobile devices is known as mHealth [10] and mobile PHR apps as mPHRs. The adoption of mPHRs allows patients to access their medical information in any place at any time [5].

Although patients are willing to use PHRs [11], their use rate is low. Legal concerns, privacy, usability challenges, the complexity of PHR systems, organizational boundaries or cultural issues are just some of the barriers to the adoption of PHRs [12–14]. Although various models with which to evaluate the usability of mHealth have been proposed [15],

usability has been identified as one of the main issues that should be further investigated as regards PHR adoption and use [16,17]. Usability factors are a primary handicap to mHealth adoption, and research should focus on the factors related to the attitudes and the use of the PHRs [15–17].

According to the ISO 9241–210 standard, usable systems can provide a number of benefits such as improved productivity, enhanced user well being, avoidance of stress, increased accessibility and reduced risk of harm [18–21]. Healthcare information systems have a high number of usability flaws which block their use [22]. With regard to the usability issues of mobile applications, Whitlock and McLaughlin have identified usability problems with some blood glucose tracking apps that may limit their accessibility, in particular: small texts, thin lines on graphs or poor contrast [23].

In order to mitigate these usability barriers, guidelines for mobile devices can help developers to accomodate their mPHR apps to the human interaction principles [5]. MPHRs should be adapted to user needs by considerating the characteristics of mobile devices such as limited hardware with slow operating systems, variable connectivity, no physical keyboard, small screens, and low battery performance.

The aim of this paper is to analyze the usability of 24 mPHRs for Android and iOS that were selected by means of a analysis process contruction which was based on the Systematic Literature Review (SLR) approach to ensure the accuracy and impartiality of the process [24]. A questionnaire based on the Android Design Guidelines [25] and the iOS Human Interface Guidelines [26] and composed of 13 questions was developed and used to assess the compliance of the 24 apps selected. To the best of our knowledge, no recent study has analyzed the usability of PHRs in any format (USB, Web or Mobile).

The article is organized as follows: the Background section provides a summary of the background of mobile PHRs and introduces the official iOS and Android usability guidelines. The Method section shows how the review was planned, explaining the method used and how it was carried out. The results obtained are synthesized and the research questions are answered in the Results section, while the Discussion section shows a discussion of our findings and presents the limitations of this study. Our conclusions and future work are presented in the Conclusions section.

Background

This section presents and studies the current state-of–the-art of mPHRs and introduces the official design and usability guidelines of iOS and Android.

Mobile personal health records

The International Organization for Standardization (ISO) defines Electronic Health Records (EHRs) as a repository of information regarding the health status of a subject of care in computer processable form, stored and transmitted securely, and accessible by multiple authorised users [27]. EHRs allow authorized clinicians from different care organizations to share information such as the diagnoses, medications, immunizations and medical histories of a mutual patient. PHRs contain the same type of information as EHRs, except that PHRs relay on the patients to control their own data, allowing them to access, manage, record or share relevant events for their health conditions [16,28]. If a PHR is linked to a healthcare provider or to an EHR, then it is termed as a tethered PHR, but if the PHR is not connected and requires users to provide their health information, it is termed as an untethered PHR [12,29]. The ISO 20514 divided PHRs into 4 general categories: (1) a self-contained EHR maintained by a third party; (2) a self-contained EHR maintained by the patient; (3) a component of an EHR maintained by a health provider and controlled at least partially by the patient; (4) a component of an integrated EHR maintained by the patient [27].

From a technological point of view, PHRs have undergone a rapid growth in the area of health information [30]. New models of intelligent PHRs (iPHRs) have been proposed to increase both functionalities and usability [31–33]. However, the main movements behind the growing popularity of PHRs include the Health 2.0 effort and the web-based personal medical home model [7]. The demand for more accessible and portable options has increased with patients' needs. Lafky and Horan [34] identified that the most important motivation for PHR users with disabilities is being able to use the system for support in emergencies, thus requiring portable solutions [17].

Mobile PHRs have traditionally included USB drives, disks and other forms of storage devices which have significant limitations [35]. Smartphones and tablet computers have emerged as a new potential platform for PHRs [5] thanks to their ever-increasing powerful technical capabilities, their widespread adoption and the users' attachment to their personal devices [36]. According to Fogg [37], we spend even more time with our phones than in our workplaces and with our sentimental partners.

Design guidelines

A rich user experience is a key to the success of any kind of application (desktop, web or mobile apps), which is why there is such a huge amount of research into user interface (UI) design and human interface principles. A Google survey of mobile users found that 79 % of people who do not like what they find on one site will move on to another site, and that

75 % of users prefer user-friendly sites [38]. For mobile apps, there are specific guidelines that deal with the characteristics of mobile devices. The World Wide Web Consortium (W3C) has published a recommendation document concerning mobile web application best practices [39]. The user experience is one of the six categories classified as best practices in these guidelines. Designing for multiple interaction methods or minimizing latency are some of the global statements in the user experience category. Nilsson has also proposed design patterns for the UI of mobile apps in order to solve several specific problems, such as how to handle dialogs when the keyboard is hidden, mechanisms for entering text and/or how to present elements in lists [40].

From our point of view, a good approach with which to ensure a standard design is to examine the official UI guidelines of the existing mobile operating systems. For instance, if a mobile app is being developed to run on an iOS device, it should follow the patterns created for that operating system. Native apps and the operative system itself follow these patterns. Users are accustomed to navigating through different apps in a similar way, so if apps behave differently, users may get confused [41]. Note that 48 % of users who are dissatisfied with the performance of a mobile app will not use that app again.

The most popular mobile operating systems are: Android, iOS, Windows Mobile and Blackberry. However, two of them clearly stand out from the others: Android and iOS, which between October 2012 and September 2013 [1] led in mobile data traffic volume with 33 % and 23 % of the market, respectively. With regard to the number of devices, according to the International Data Corporation (IDC) [42], Android and iOS combined had 91.1 % of the worldwide smartphone OS (operating systems) market share in the fourth quarter of 2012. Android is ranked number one, with 70.1 % of market share in the fourth quarter of 2012. It is followed by iOS with 21 %; Blackberry, 3.2 %; Windows Mobile, 2.6 %; Linux, 1.7 %; and others 1.3 %. The Google Play Store and the Apple App Store have around 800,000 apps each [9].

Android and iOS have online documentation, which includes a section concerning UI design and targeted developers. Android design guidelines [25] are divided into four main sections: (1) Get Started, which concerns design principles and UI overview; (2) Style, which deals with typography, colours or iconography; (3) Patterns, which concerns app structure, navigation or the action bar; and (4) Building Blocks, which deals with UI elements such as lists, buttons or dialogs. The Android guidelines also provide a section to enable the downloading of icon packs and fonts, in addition to a video section. The iOS guidelines [26] are divided into five sections: (1) UI Design Basics, concerning navigation, typography, colours or iconography; (2) Design Strategies, regarding design principles; (3) iOS Technologies, which is related to several iOS services like passbook or iCloud; (4) UI Elements, which concerns controls or bars; (5) Icon and Image Design, which deals with the sizes and resolution of images and icons.

When developing an mPHR app, these design guidelines should be examined and followed to create a user-friendly mobile app. Since usability is one barrier to the adoption of these apps [15–17], the aim of this study is to evaluate whether the existing mPHR apps adhere to the official design recommendations.

Method

This section describes the method used to search for, select and evaluate the mPHRs. The method applied, which is shown in Fig. 1, is based on and derived from the well-known SLR process [24]. PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analysis) group reporting guidelines, whose objective is to help authors improve the reporting of systematic reviews, are followed in this paper [43]. The first step of the method consists of establishing the research questions (RQ) that will guide the successive phases. The objective of the second step is to select the sources from which the candidate apps will be extracted and to define the terms used in these sources to carry out the search. In the third step, the eligibility criteria is defined and applied to the candidate apps in order to obtain the apps eventually selected. In the fourth step, an assessment questionnaire is detailed and employed to evaluate of the apps selected. Usability evaluation methods [44] can be conducted by experts, users or a combination of both [45]. Experts who are experienced in usability testing are frequently asked to evaluate the design of user interfaces, which are usually based on heuristic methods and guideline reviews, when usability inspection methods are conducted [44]. Expert based evaluation has also been identified as a method that can be used to conduct usability evaluations for mobile devices [46] and has been employed to evaluate usability in mobile health applications [47,48]. In this article we use a guideline review approach. The results of which are analyzed in the fifth and final step.

Research questions and protocol

In order to analyze the usability of mPHRs through their compliance with the official guidelines of Android and iOS operating systems, four research questions have been formulated which are shown in Table 1.

Sources and search terms

The app repositories selected are: Apple App Store and Google Play. These two app stores are the most popular, and

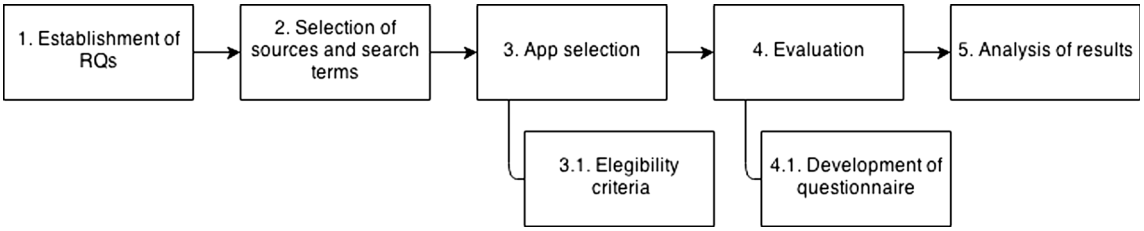

Fig. 1 Method used to search for, select and evaluate the mPHRs

they are the leaders as far as the number of apps is concerned. With regard to medical apps, the Apple App Store has around 20,000 apps while Google Play has around 8,000 apps [9].

The PICO criteria was used to define the search string: population, intervention, comparison and outcome [49]. The resulting set should have the maximum possible coverage, but should also be of a manageable size. The search string was defined as follows:

"*PHR*"*OR*"*personal health record*"

The search process took place in October 2013. This process was conducted by applying the search string shown above to both sources, using their search utility, which is applied to the title and description of the apps.

Eligibility criteria and application selection

The aim of the selection process was to find mPHRs that are relevant to the objective of this research. Each app was evaluated to decide whether it would be included in the pool of apps studied. This process was performed using the following inclusion criteria (IC). Meeting all the inclusion criteria was mandatory for an app to be selected.

- IC1: Apps in the Health category of App Store or Google Play that are PHRs.
- IC2: Apps that have a free version.
- IC3: Apps that have been updated after the 1st of January 2013.

IC1 selects the PHR apps that were classified by their developers in the health category. IC2 selects the free apps since they are available to anyone. Note that paid apps might have a more advanced functionality, and that full functionality is sometimes provided after accepting an in-app advertisement for free usage [50]. However, free apps are more popular because there is a negative correlation between price and downloads [51]. A survey conducted by Harris Interactive in 2010 reported that 95 % of the U.S. adult population prefers free apps [52]. Observe that around 80 % of the apps downloaded from all of the app repositories are free [53]. According to the Mobile Health Market Report 2013–2017, released in March 2013, the top 10 mHealth apps on Android and Apple platforms generate up to 4 million free downloads as opposed to 300,000 paid downloads [4] per day. Finally, IC3 is necessary to ensure that the app is being maintained and is not in a state of abandonment. A frequent release cycle allows developers to engage users by extending functionality or security, and fixing bugs. Although there is no magic number as regards the frequency of app releases in a year, at least one new app version should be released per year [54].

The initial search phase obtained a set of 203 candidate apps. After applying the aforementioned ICs, 35 mPHRs were selected. For example, mPHRs like *Stabilix PHR Pro* for Android or *Capzule PHR* for iOS were not included because they are not free apps. Other mPHRs like Minerva PHR Viewer for iOS were not included because their last update was before 2013. These 35 mPHRs were reduced to the 24

Table 1 Research questions

	Research Question	Motivation
RQ1	What are the most usable mPHRs for Android and iOS?	This question analyzes the apps evaluated individually.
RQ2	What are the differences between Android and iOS mPHRs as regards usability?	This question analyzes the way in which the mPHRs differ when programmed for iOS and/or Android.
RQ3	Which app structures are most commonly used in the mPHRs and how do they improve usability?	This question provides information on the most common means used to structure an mPHR. Appropiate structures make easy-to-navigate apps that enhance the usability.
RQ4	To what degree do the mPHRs comply with the usability recommendations proposed for Android and iOS?	This question defines the main goal in this article, providing an objective result on the usability status of mPHRs.

mPHRs eventually selected for the review after applying the exclusion criteria (EC).

- EC1: Apps that have problems when they are installed or have critical runtime errors that do not allow a good evaluation of the app.
- EC2: Apps that depend entirely on an external service and cannot be evaluated as a single mobile app (full-tethered mPHRs).

Those apps that match any of the inclusion criteria are no longer candidate apps. For example the PHR My Health Diary for iOS was excluded because the app is only available in Indian's AppStore and could not be installed. The PHR named MHA Mobile was excluded because the installation package is not correctly signed and an error appeared when attempting to install the app. The complete list of discarded apps can be consulted in Appendix I.

The selection process was carried independently by two authors through the use of spreadsheets. There were no disagreements between the two authors during the selection process since the inclusion and exclusion criteria are clear and objective. Figure 2 shows the results of the complete mPHRs selection process.

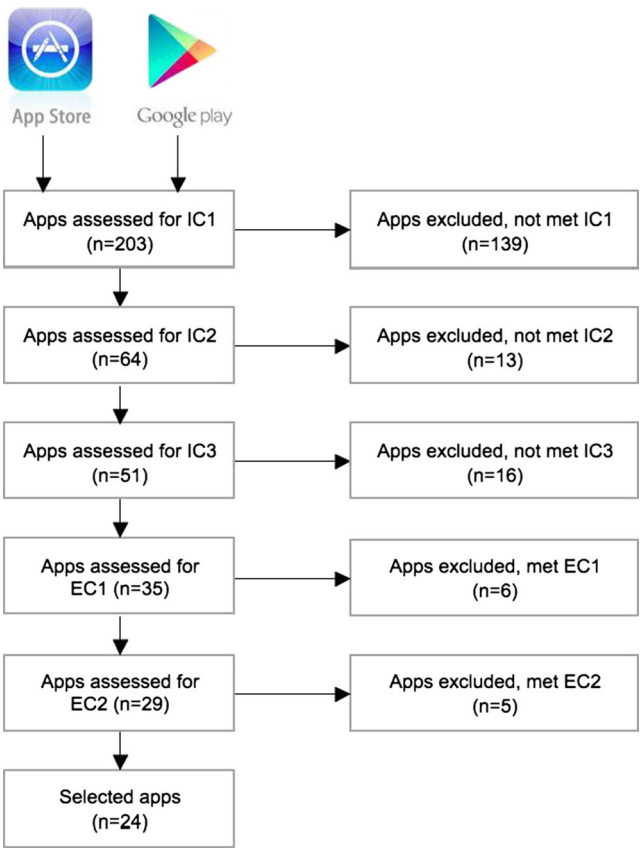

Fig. 2 PRISMA flow diagram

Data extraction strategy

The data extraction was carried out by using the questionnaire shown in Table 2. The questionnaire was developed on the basis of: (1) known usability standards and recommendations [18,39]; (2) related literature [15,20,21,40], and (3) the official design guidelines for Android and iOS [25,26]. The form is divided into three blocks: style, behavior and structure. This architecture is based on the three layers of web design: style or presentation, behavior, and content or structure [55]. An online survey was conducted to validate this questionnaire between the 20th and 25th of April of 2014 using Google Forms [56]. The survey was taken by 22 mobile users who had diverse ages, gender, nationality and educational backgrounds. For quantitative studies, Jakob Nielsen recommends that at least 20 people are necessary if statistically significant results are to be obtained [57]. The participants were aged between 18 and 51, with a mean age of 30. The subjects were asked to fill in a questionnaire that contained 13 questions that were answered by selecting numbers on a five-score Likert-type scale of 1–5. The average acceptance of the questions was 71.24 % (mean: 3.85). The question with the highest level of agreement was Q2.5 with 81.82 % (mean: 4.27; SD: 0.88).

Table 2 Questionnaire and survey results

Question	Survey
Q1. Style.	
Q1. 1. Is the writing style simple and informal and is the second person used to talk to the user?	3.64
Q1. 2. Are pictures used to explain ideas?	3.95
Q1. 3. Are pre-defined icons used for common actions?	4.18
Q1. 4. Does the app adapt to both horizontal and vertical orientations?	3.59
Q2. Behavior.	
Q2. 1. Are the user preferences learned over time?	3.45
Q2. 2. Do the elements react to the user's gestures by changing color or illumination?	3.64
Q2. 3. Are there confirming messages showing warning information related to actions that the user needs to consider?	3.55
Q2. 4. Are there acknowledging messages to let users know that the action they have invoked has been completed?	4.23
Q2. 5. Do long tasks show non-stationary activity indicators?	4.27
Q3. Structure.	
Q3. 1. Is the app loaded immediately without any splash screen or startup experience?	4.00
Q3. 2. Is the login delayed to allow the user to use a particular functionality first?	3.59
Q3. 3. Are suggested structure patterns used: action/tool bar, tab bar (top for Android, bottom for iOS), spinner or navigation drawer?	3.73
Q3. 4. Is the navigation consistent when moving between hierarchical screens?	4.23

The question with the lowest level of acceptance was Q2.1 with 61.36 % (mean: 3.45; SD: 1.18).

Each application was evaluated independently by two authors in order to answer the research questions. Each question was scored as follows:

- 1 point, if the answer to the question'are more than 70 % of use cases applicable to the app?' is positive.
- ½ point, if the answer to the question'are less than 70 % of cases and more than 30 % of use cases applicable to the app?' is positive.
- 0 points, if the answer to the question'are less than 30 % of use cases applicable to the app?' is positive.

A template containing the data that should be extracted was designed in the form of a spreadsheet. Each application was independently assessed by the first two authors of this paper to evaluate each of the assessment questions. The inter-rater agreement between the two results obtained was calculated using the Cohen's Kappa coefficient. The Kappa coefficient assesses how well two independent observers classify subjects. The coefficient obtained was 0.97 and, since it is close to 1, this indicates an almost perfect level of agreement [58].

The apps were classified into five quality groups according to their score. A variation of the equal width interval binning was used [59]. Observe that the lower and upper bins are shorter than the others in order to discriminate extreme scores: (1) Very High, (2) High, (3) Moderate, (4) Low and (5) Very Low. The score limits for each group are defined in Table 3.

Each usability assessment (UA) question was drawn up after studying both guidelines. Questions regarding usability were extracted while other recommendations regarding aesthetic features were discarded. Sections related to widgets or compatibility are not applicable to our study. Sections related to themes, colors or typography and notifications are specific to the OS and it was therefore unfeasible to measure them. The sections discarded from Android guidelines were: Style|Metrics and Grids, Style|Typography, Style|Themes, Style|Color, Patterns|Notifications, Patterns|Widgets, and Patterns|Compatibility. Those discarded from iOS guidelines were: UI Design Basics|Modal Contexts, UI Design Basics|Animation, UI Design Basics|Color and Typography, and iOS Technologies. In Table 4, each usability assessment question is mapped onto a section of each guideline.

Table 3 Quality groups

Score	Quality Group
12–13	Very High
8,5–11,5	High
5–8	Moderate
1,5–4,5	Low
0–1	Very Low

Results

This section describes the results related to the data extraction performed. These results are presented as follows.

Table 5 shows the basic information regarding each of the apps selected: Application Name (full name of the app), OS (operating system Android and/or iOS), Structure Pattern (what structure pattern is used in the top-level menu of the app), Orientation (this indicates whether the app permits both portrait and landscape orientations), Developer Name (developer listed in the app information available on the market), App URL (link to Google Play or App Store for each app, presented using the Google URL Shortener). Of the 24 apps selected, 10 have been developed for the Android system and 14 for iOS. The tabs pattern is used by 11 of the mPHRs as the top-level menu and only two apps, both published by the same developer, use a drawer structure. With regard to the orientation, 10 of the 24 apps permit both orientations: portrait and landscape. The fact that most of the mPHRs with the same or a similar name belong to the same developer can also be observed in Table 5.

Note that none of the PHRs identified in a previous study by Kharrazi et al. [5] were selected. The paper in question evaluated the features and functionality of nineteen mPHRs: 8 for iOS, 5 for BlackBerry, and 6 for Android. The 5 apps for BlackBerry were discardedin accordance with our IC1 inclusion criterion. Upon considering the IC1 inclusion criterion, 8 apps were not selected because they are not free, while the remaining 6 mPHRs no longer exist on the official apps markets (EC2 exclusion criterion).

Table 6 presents the results of the questionnaire for each mPHR app. Each row represents the evaluation of an app, indicating the points obtained by the app in each UA question. The maximum score for an app is 13 points (number of questions in the questionnaire). The Total column represents the total score obtained by the app. The final Total (%) column contains the total score percentage for a more intuitive examination. Hence, the app with the highest score is iTriage Health for iOS, which scores 11 points out of 13. Only two apps have obtained a score below 50 %. Each column that represents a UA question can achieve the maximum score of 24 points (number of mPHRs). The Total and Total (%) rows represent the total score of the question. For example, Q2.5 is the question with the highest score: 23.5 points out of 24. The question with the lowest score is Q3.2: 7 points out of 24.

Table 7 presents, in terms of percentages, the amount of apps that scored in each quality group defined in Table 3. All the mPHRs are included in the High or Moderate groups,

Table 4 Mapping between UA questions and guidelines

UA question	Android guideline section	iOS guideline section	Guidelines recommendation
Q1.1	Style Writing Style	UI Design Basics Terminology and Wording	Be simple and friendly. User may skip sentences if they are long.
Q1.2	Get Started Design Principles	UI Design Basics Layout	Pictures are more efficient than words to explain ideas.
Q1.3	Style Iconography	UI Design Basics Icons and Graphics	Try to use the built-in icons to perform common tasks.
Q1.4	Patterns Multi-pane Layouts	UI Design Basics Integrating with iOS	Screens should have the same functionality regardless of orientation.
Q2.1	Get Started Design Principles	Design Strategies From Concept to Product	Learn user preferences so he or she does not have to make the same choices over and over.
Q2.2	Style Touch Feedback	UI Design Basics Interactivity and Feedback	Use color and illumination to provide a visual response to user touches.
Q2.3	Patterns Confirming & Acknowledging	UI Elements Temporary Views	Ask users if they want to proceed with the action they invoked.
Q2.4	Patterns Confirming & Acknowledging	UI Elements Temporary Views	Users need some feedback of their actions.
Q2.5	Building Blocks Progress & Activity	UI Elements Controls	Reassure users that their task has not stalled.
Q3.1	Patterns Help	UI Design Basics Starting and Stopping	Present useful content immediately to give a better user experience.
Q3.2	Patterns Accessibility	UI Design Basics Starting and Stopping	Users often abandon apps when they need to log in to do anything useful.
Q3.3	Patterns App Structure	UI Design Basics iOS App Anatomy	Implement a structure that supports the purpose of your app.
Q3.4	Patterns Navigation	UI Design Basics Navigation	Make the app's navigation predictable and reliable.

signifying that the 100 % of them have scored between 5 and 11.5 points out of 13. Figure 3 presents the results of the mPHR apps based on the score obtained in each block of the questionnaire: Q1, Style; Q2, Behavior; Q3, Structure. Figure 4 presents the results of each question based on the score obtained by the mPHRs in that question.

Discussion

This section discusses the results and the main findings of this study. Recommendations for mPHRs developers and stakeholders are also proposed.

RQ1: What are the most usable mPHRs for android and iOS?

The results of the evaluation of the mPHRs in Table 6 help to answer this question.

The app with the highest score is *iTriage Health* for iOS with a score of 11 out of the 13 questions assessed. However, the app does not use any of the structures for the top-level menu suggested in the guidelines, and has a splash screen that delays access to the content.

Health Companion and *MTBC PHR,* both for iOS, tie in the second position with 10.5 points, only 0.5 below the highest score. Like *iTriage Health* for iOS, these apps only achieve a score of 50 % in the structure block. Both apps only score half a point in Q2.2 owing to the fact that some UI elements do not respond to user interaction.

Only two mPHRs obtained less than half of the maximum score. These apps are *CareFlowPHR* and *Track My Medical Records*, both for Android, with scores of 6 and 5.5 points, respectively. The lowest ranked iOS application is *MyClinicNotes* with a score of 6.5, only half a point above *CareFlowPHR* for Android.

RQ2: What are the differences between android and iOS mPHRs as regards usibility?

The interpretation of the results obtained in Table 5 and Table 6 regarding the evaluation of the mPHRs and the comparison of apps by the same author can help to answer this question.

While iOS apps achieve an average score of 73 % points, Android mPHRs have a lower average score, with 61 % of the points. The Kolmogorov–Smirnov test was used to check that the mPHRs scores had a normal distribution, while the Levene test was employed to verify the equality of variances in the two groups of scores analyzed. With the usual 95 % confidence interval, the student's *t*-test for independent samples determined that the differences found in usability ($t(22)=1.869$, $p=0.75$), style ($t(22)=1.635$, $p=0.116$), behavior ($t(22)=0.858$, $p=0.4$) and structure ($t(22)=1.612$, $i=0.121$) are not statistically significant.

Table 5 mPHR information

Application Name	OS	Structure Pattern	Orientation	Developer Name	App URL
CareFlowPHR	and	None	Yes	CareFlow, LLC	http://goo.gl/RQrREM
CareSync	iOS	None	No	Continuum Labs, Inc.	http://goo.gl/FNW5UI
EasyMed Medical Passport	and	Tabs	Yes	EasyMed Services Inc	http://goo.gl/iMOqfA
EasyMed Medical Passport	iOS	None	Yes	EasyMed Services Inc	http://goo.gl/ewxbUh
Health Companion	iOS	Tabs	No	Health Companion, Inc.	http://goo.gl/3jQ8HO
Health suite	and	None	Yes	Mitgun	http://goo.gl/SVtc8V
Health2me	and	Tabs	Yes	EdgeHealth	http://goo.gl/fjJiHp
Health2me	iOS	Tabs	No	Javier Vinals	http://goo.gl/HqgSBJ
HealthStylus	and	Tabs	Yes	Valethi Solutions Pvt. Ltd.	http://goo.gl/KZkaqH
HealthStylus	iOS	Tabs	Yes	Valethi Solutions Pvt. Ltd.	http://goo.gl/hTaFB7
iBlueButton	iOS	Tabs	No	humetrix.com	http://goo.gl/hK6FnW
iTriage Health	and	None	No	Healthagen LLC	http://goo.gl/nGEaZf
iTriage Health	iOS	None	No	Healthagen LLC	http://goo.gl/0MjANl
LifeCard Health Record	iOS	Tabs	No	Global Health Ltd	http://goo.gl/sXkbnO
MTBC PHR	and	None	No	MTBC Dev Team	http://goo.gl/ho5KIg
MTBC PHR	iOS	None	No	MTBC	http://goo.gl/4hQOgE
My Health Diary	and	Tabs	Yes	NeedStreet	http://goo.gl/AQ4erU
MyClinicNotes	iOS	None	No	Convortex, Inc.	http://goo.gl/ZJJMnQ
MyMx Personal Health Record	iOS	Tabs	No	University of Western Aust	http://goo.gl/n68lfH
MyWellnessApp	iOS	Tabs	No	Pug Creative Tech, LLC	http://goo.gl/POf7Zw
Onpatient Medical Record PHR	and	Drawer	No	DrChrono.com Inc.	http://goo.gl/uq3years
OnPatient Personal Health Record	iOS	Drawer	No	DrChrono.com Inc.	http://goo.gl/VRThzB
Personal Health Record - Lite	iOS	None	Yes	Ahmed Almutairi	http://goo.gl/CDOyj0
Track My Medical Records	And	None	Yes	Digimia LLC	http://goo.gl/L5JlSy

Nevertheless, the top 5 in the classification of the applications is crowded with iOS apps. *MyWellnessApp* is the only Android app that manages to enter the top 5 in the 4th position. The biggest difference between the applications for both platforms studied in the evaluation can be found in the Q3 block concerning the structure, in which the difference in the average rises to 17 % in favour of iOS apps.

iOS, with its programming language Objective-C and its development environment Xcode, has always been very focused on the user experience and facilitates the creation of engaging and dynamic user interfaces [26]. However, the interface builder most commonly used for Android (Eclipse and Android Studio) and the link between code and the user interface needs improvement if it is to be as good as Xcode and its storyboard approach [60]. Experimental research has shown that the UI design and implementation is a more difficult process in Android than in iOS [60].

Six of the mPHRs evaluated (*MTBC PHR, EasyMed Medical Passport, Health2me, HealthStylus, iTriage Health* and *OnPatient PHR*) provide both iOS and Android versions, which are created by the same developer with the same or similar names and same functionalities. Figure 5 presents the score differences between each version. In half of the cases, the highest score goes to the Android version, while in the other half it goes to iOS. The highest difference is 2.5 points out of 13 in *OnPatient PHR* app, while the smallest one is half a point in the *MTBC PHR* apps. The *OnPatient PHR* app for iOS does not have the same functionalities as the Android version. The iOS version of this app is an improved and more completed version than the Android one, which does not use any icons, and when the user presses the device back button it logs out. The use of icons in mobile interface contributes toward improving the user experience [61]. The importance of using icons that are known has already been proven to be useful. Icons can sometimes be ambiguous and may cause various interaction problems [62]. Default icons are usually well known by the users and can help reduce this problem.

Another remarkable example is the *iTriage Health* app. This mPHR has a higher score than the rest of the apps, although only for its iOS version: 85 % (11 points in Fig. 5) as opposed to 73 % (9.5 points in Fig. 5) of the Android version. Both apps are very similar and lead to a deep

Table 6 Questionnaire results

Application Name	OS	Q1.1	Q1.2	Q1.3	Q1.4	Q2.1	Q2.2	Q2.3	Q2.4	Q2.5	Q3.1	Q3.2	Q3.3	Q3.4	Total	(%)
CareFlowPHR	and	1	1	½	0	0	1	0	1	½	0	0	0	1	6	46 %
CareSync	ios	1	1	1	1	1	1	1	1	1	0	0	0	1	10	77 %
EasyMed Medical Passport	and	1	1	½	½	1	1	0	1	1	0	0	½	1	8.5	65 %
EasyMed Medical Passport	ios	1	1	½	½	1	1	1	1	1	0	0	½	0	7.5	57 %
Health Companion	ios	1	1	1	1	1	½	1	1	1	0	0	1	1	10.5	80 %
Health suite	and	1	1	0	½	1	1	1	1	1	0	0	0	½	8	61 %
Health2me	and	1	1	1	1	0	1	1	0	1	0	0	1	0	8	61 %
Health2me	ios	1	1	0	1	0	1	1	0	1	0	0	1	0	7	53 %
HealthStylus	and	1	1	½	1	½	1	1	1	1	½	0	½	1	10	77 %
HealthStylus	ios	1	1	½	1	½	1	1	0	1	0	0	1	1	9	69 %
iBlueButton	ios	1	1	1	1	½	1	1	½	1	0	0	0	1	9	69 %
iTriage Health	and	1	1	1	1	1	1	0	1	1	0	1	0	½	9.5	73 %
iTriage Health	ios	1	1	1	1	1	1	1	1	1	0	1	0	1	11	85 %
LifeCard Health Record	ios	½	0	1	1	1	½	1	1	1	0	0	1	1	9	69 %
MTBC PHR	and	1	1	½	1	1	½	1	1	1	0	1	0	1	10	77 %
MTBC PHR	ios	1	1	1	1	1	½	1	1	1	0	1	0	1	10.5	80 %
My Health Diary	and	1	1	1	1	1	0	0	0	1	0	0	1	1	8	61 %
MyClinicNotes	ios	1	0	½	1	0	1	0	1	1	0	0	0	1	6.5	50 %
MyMx Personal Health Record	ios	½	1	1	1	0	1	0	1	1	0	1	½	1	9	69 %
MyWellnessApp	ios	1	1	½	1	0	0	1	1	1	1	1	1	1	10.5	80 %
Onpatient Medical Record PHR	and	1	0	½	1	0	1	0	1	1	½	0	1	0	7	53 %
OnPatient Personal Health Record	ios	1	1	1	1	0	1	0	1	1	½	0	1	1	9.5	73 %
Personal Health Record - Lite	ios	1	1	1	½	0	1	1	1	1	0	1	0	1	9.5	73 %
Track My Medical Records	and	½	0	0	1	1	0	0	1	1	0	0	0	1	5.5	42 %
Total		22.5	20	16.5	21	13.5	19	14	19.5	23.5	2.5	7	11	19		
Total (%)		94 %	83 %	69 %	88 %	56 %	79 %	58 %	81 %	98 %	10 %	29 %	46 %	79 %		67 %

navigation hierarchy, but whereas the iOS app has a top bar that provides the information concerning the levels of the hierarchy and has a direct button to return to the main menu, the Android app does not. Navigation should be consistent throughout the app in order not to disorient the user [63].

There are two other apps, *Health Companion* for iOS and *My Health Diary* for Android, which have an Android and an iOS version, respectively. *Health Companion* for Android and *My Health Diary* for iOS were discarded because they have a geographical restriction as regards being able to download and install them. Finally, the *Personal Health Record – Lite* app for iOS also has an equivalent app for Android. The Android version did not meet IC3 since it has not been updated since 2012.

Table 7 Quality groups' percentages

Quality Group	% of apps	∑% of apps
Very High	0 %	0 %
High	63 %	63 %
Moderate	37 %	100 %
Low	0 %	100 %
Very Low	0 %	100 %

Appendix I

RQ3: Which app structures are most commonly used in the mPHRs and how do they improve usability?

In order to answer this question, we considered both the results of the usability assessment questions in the Q3 block and the basic information extracted from the Table 5 mPHR information. While 54 % of apps used one of the structure patterns suggested in the guidelines (action and tool bars, fixed tab bars, spinners and navigation drawers [25,26]), only 37 % of them used the patterns correctly according to the guidelines. One of the differences found in the iOS and Android guidelines is precisely what has led these apps not to attain the full score in this question: in iOS, the tabs are

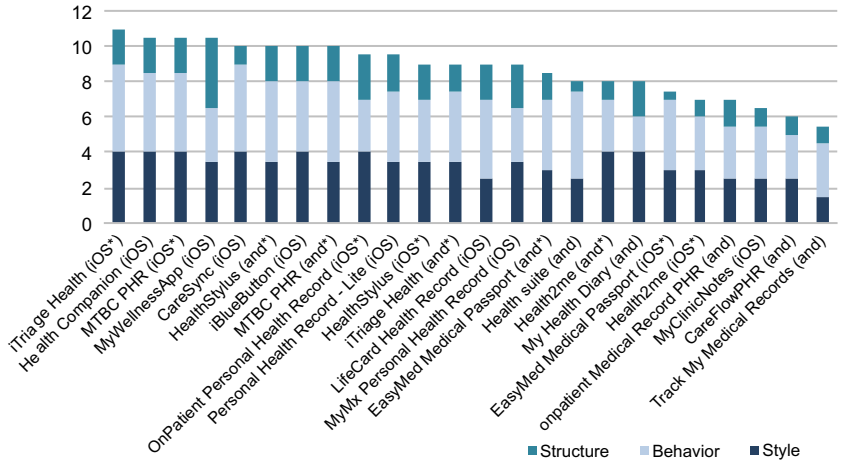

Fig. 3 mPHRs classification. * App with both iOS and Android versions

supposed to be situated at the bottom of the screen, while those of Android apps should be at the top [25,26].

The navigation tab pattern is that most frequently used in the mPHRs studied. Tabs provide a powerful mechanism with which to navigate through different pages [64]. Of the 13 apps that attained a higher score than 0 in Q3.3, 84 % of them used fixed navigation tabs. Navigation drawers are panels that are accessible from the edge of the screen and display the app's main navigation options and are often recommended as a top-level navigation system [65]. Only two applications, one for Android and one for iOS and both developed by *DrChrono.com Inc.,* used the drawer navigation pattern: *onpatient Medical Record PHR* and *OnPatient Personal Health Record*.

46 % of apps meanwhile used a pattern that was not included in the guidelines, most of these being a simple list, and some offering a classical springboard also known as launchpad. Lists as a top-level page are largely deprecated and their use is only suggested in second and third-level pages, which are often used to expand on details for a content section [66]. In some mPHRs, the Springboard or launchpad pattern was also used as the main page for mobile apps since it provides a rapid means to access various functionalities. Android and iOS users are already familiar with these interactions [66]. However, one important disadvantadge for the user experience has been found: having to go back to the main top-level page to access a different functionality. In both guidelines the suggested patterns fix the problems of lists and springboards, since most of the functionalities are available on every page in the application [64].

The use of toolbars or spinners is not frequent. A toolbar, also called an action bar, provides a space dedicated to important actions [25]. In Android, the action bar is placed at the top of the screen and can include the navigation elements. An action bar in Android has a specific organization from left to right: the navigation action, app icon, action buttons and the action overflow button. In iOS, toolbars are displayed at the bottom of the screen and do not enable navigation, merely providing users with controls with which to act on the current screen [26]. MPHRs store information about illnesses, doctors or medications, and are therefore a great scenario for the use of toolbars. Toolbars can support these functionalities by easily providing users with the most useful actions [66].

A spinner is a drop-down menu that allows users to switch between views of an app. Spinners are recommended to

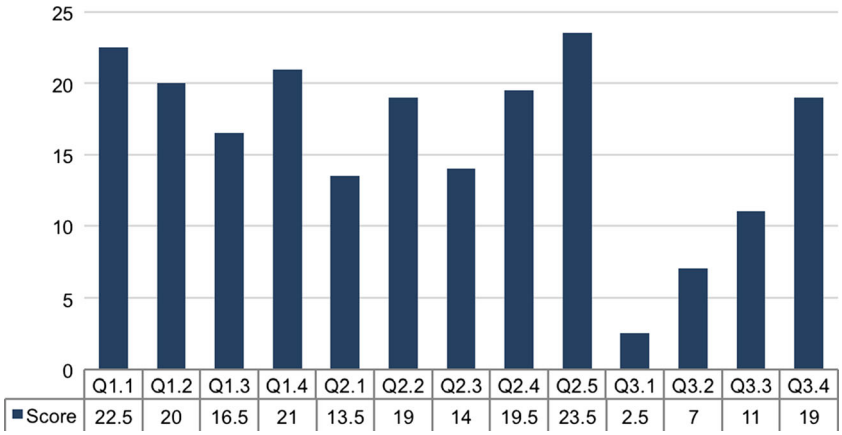

Fig. 4 Classification of questions

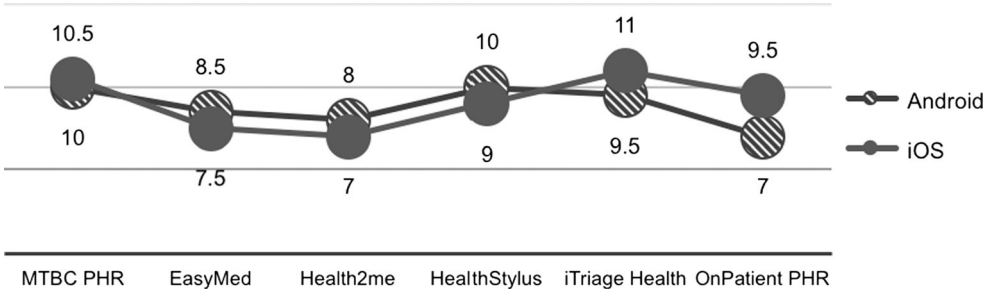

Fig. 5 Differences in apps for Android and iOS

switch between different views of the same data set or data sets of the same type [25]. The use of spinners to switch between different family members (data sets of the same type) and to switch the appointment view between day, week or month (views of the same data) may improve the usability of the mPHRs analyzed.

RQ4: To what degree do the mPHRs comply with the usability recommendations proposed for android and iOS?

This question was answered by employing the usability assessment questionnaire, whose results are shown in Table 6 and in Table 7. The total score percentage of the selected mPHR apps analyzed is 67 %. This signifies that usability is still one of the barriers to mPHRs adoption [15–17], and it should be considerably improved. Figure 6 represents the average score percentage per block of the questionnaire.

Q1 style The highest punctuated question in this block is Question Q1.1, which is also the second question in the global ranking, with a score of 94 %. This question examines the writing style. Health literacy has been identified as an acceptance barrier in PHRs users, which establishes the importance of this characteristic, particularly in health related applications [67]. Only 12 % of apps obtained ½ a point rather than the full score. *LifeCard Health Record* for iOS has ½ a point because it has some words in a different language while the rest of the app is in English. *MyMx Personal Health Record* for iOS exploits the use of abbreviations, which makes the texts and options difficult to understand. An abbreviation may have more than one meaning and might be unfamiliar to those users who do not have much expertise in health. The use of abbreviations in medical practices causes numerous medical errors [68]. PHRs should use concepts that are familiar to the user rather than medical terms [63]. *Track My Medical Records* for Android also has ½ a point because the welcome screen contains too much text and the same tooltips are shown more than once.

The third question in the ranking is Q1.4, 88 %. This question checks whether the app is adapted to portrait and landscape orientations. These features are particularly interesting since accelerometers can be found in any modern smartphone, thus permitting manifold scenario-awareness apps that improve gaming, health monitoring, among several other uses [69]. Orientation changes can be handled by supporting them and adapting the screen design to both portrait and landscape orientations, or by restricting them and allowing just one orientation. Although 14 out of 24 apps do not support the orientation change, they do not have an incorrect usability behavior according to the guidelines [25,26]. In these cases, a restriction policy is used to adapt the orientation change. Finally, only *CareFlowPHR* for Android has no points. This app supports the orientation change, but when the user performs the change, the app logs out and returns to the login screen. The apps that have attained ½ a point have blank spaces and poor formatting in the horizontal orientation.

Q2 behavior The most remarkable recommendation in this block is related to question Q2.5, which achieves the highest grade of compliance: 98 %. This question evaluates whether the apps show non-stationary activity indicators when performing time-consuming tasks. Providing progress

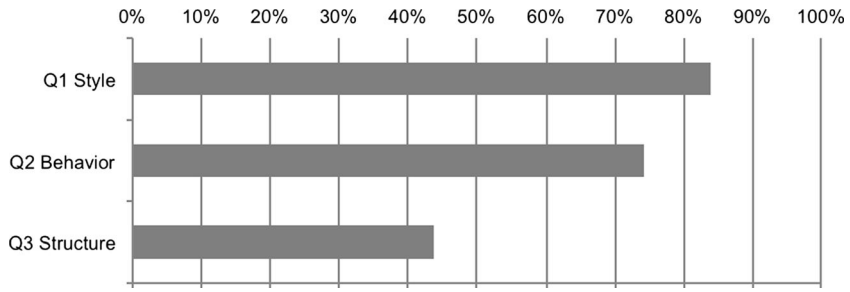

Fig. 6 Average score per block

information improves the users' experience [70]. Only one app, *CareFlowPHR* for Android, does not obtain the maximum score (only ½ a point). This app shows an activity indicator when opening some screens, yet this does not occur in the configuration panel. The configuration panel of this app behaves in a manner that the user may find confusing since two of the four available options do not work and the two correct options do not show any activity indicator.

All the activity indicators displayed in the apps are presented with unknown progress. This means that the user knows that a task is running although its remaining time is not indicated. Progress indicators that display information about how much waiting time remains affect the user's experience in a more positive manner [71]. One improvement that could be made to the mPHR apps that perform long tasks would be to provide the users with this information. Only 33 % of the apps evaluated do not execute any long tasks.

The worst question in this block is question Q2.1 with a degree of compliance of 56 %. Question Q2.1 evaluates whether the mPHR app remembers the user's data. The main flaw found in this recommendation is not saving the user credentials, so that the user has to write his user identifier and his password everytime the app is launched. Some apps (3 out of 24) obtain ½ a point because they only ask for the password or the security code.

Q3 structure Note that the three questions with the lowest score, and below 50 %, belong to the Q3 block concerning the structure of the apps. Question Q3.1 has the lowest degree of compliance, with a score of only 10 %. This question evaluates whether the app presents useful content immediately, with direct access to functionalities. 83 % of the apps achieve no points in this question because they display a splash screen that delays the loading of the first useful screen of the app. What is more, three of them present a screen in order to accept their terms and conditions the first time it is launched: *iTriage Health* for iOS and Android and *MyMx Personal Health Record* for iOS. Providing the PHR policy as a part of transparency and notice is suggested by the Health Privacy Project, which published the 10 best practices for employers offering PHRs [72,73]. The terms and conditions should not therefore be removed; however their acceptance can be delayed until the user's final adoption. Four more apps present a functionality guide at the beginning of the execution: *EasyMed Medical Passport* for iOS and Android allow the user to skip this help, while *Health2me* for iOS and Android do not. These guidelines do not introduce the app by letting the user interact with it, and only a set of images explaining the capabilities of the app is shown. As stated by Tang et al. [12], PHR providers should learn to encourage patients to use and trust their products. Separating the user from the functionalities, especially when the user is trying out the app for the first time, does not help overcome usability barriers.

Only one app obtains a full score in question Q3.1: *MyWellnessApp* for iOS. This app immediately loads a functional screen, which contains the bottom tab buttons that launch the different functionalities. Finally, three of the apps score ½ a point in Q3.1. These apps display the login screen when the app is launched. The login screen can be considered as a functional screen although it is not a desirable behavior. Since the login is required to be able to use the app, these apps obtain no points in question Q3.2. The next question with a low score (29 % of the points) is precisely question Q3.2. The guidelines suggest delaying the authentication and letting the user try out the app first [25,26]. Seven of the 24 apps obtain 1 point in this question, 4 of them delay the login and 3 of them do not have any login at all. On the contrary, the remaining 17 apps attain 0 points because they ask the users to login before they can use the app. Delaying the authentication encourages the user to first get familiar with the app. Only then, when it is strictly necessary, should the authentication process be performed. Although medical information requires stronger authentication owing to its high level of sensitivity [74], login processes usually contaminate the user experience [75]. Observe that the most common authentication method in PHR systems is based on an identifier together with a password, although even this mechanism provides weak security protection [76]. Users show concern about security and privacy, but simultaneously search for simpler authentication mechanisms such as biometric authentication [75]. Alternative authentication methods include biometric scans such as fingerprints, face, voice or retina [77]. However, biometric scans also lead to usability concerns since the accuracy of many biometric systems is not sufficiently high [78].

Limitations of the study

This study was performed by aiming for the maximum possible objectivity and accuracy. However, there may have been some threats to to the validity of the process. The search string used plus the limited functionality of both Apple App Store and Google Play search motors may have exclude apps that would have been included in the review after applying the IC and EC criteria. To alleviate this threat to the construct validity, the PICO criteria were used and a rich pool of terms was added to the search string. Relevant usability assessment questions defined in the guidelines may have been overlooked and therefore not included in this study, thus threatening the conclusion validity. These limitations could also have affected the definition of the comparative framework and the evaluation process. However, both the elicitation of the assessment questions and the evaluation of the mPHRs selected were performed by two independent authors and reviewed by the remaining authors, and the risk of a threat to the conclusion and internal validity was therefore significantly reduced. One threat to the construct validity is that the evaluation

of the mPHRs has not been performed by real users, which may have affected the representativeness of the study. The usability results could be biased in the direction of general interest in app design, which may not necessarily correspond to the opinion of real users. This threat has been mitigated by validating the questionnaire. A survey of a sample of 22 users was conducted to demonstrate the representativeness of our research. Moreover, the questionnaire is based on the iOS and Android design guidelines whose aim is to increase user retention and customer satisfaction by making it easier for users to learn how to use the application as quickly and intuitively as possible. The scope of applicability of this paper is therefore that of the official guidelines. Finally, the IC criteria exclude apps of non-free mPHRs. In order to avoid the threat to the external validity of this paper, another study including commercial apps should be carried out in future work.

Main findings

The main findings of our study are summarized as follows:

- There are no significant differences between the scores obtained by the mPHRs for iOS and for Android systems.
- The most frequently ignored facet in the mPHRs studied is that of structure.
- The navigation tabs pattern is the most frequently used structural pattern in the mPHRs analyzed. Adopting the lateral drawer pattern, which is often recommended as a top-level navigation system, is suggested.
- Toolbars are not commonly used in the mPHRs studied. Toolbars that provide users with more useful actions should be added.
- Spinners are not commonly used in the mPHRs studied. Spinners that can be used to switch between different family members or to switch the appointment view between day, week or month should be considered by developers.
- 83 % of the mPHRs studied do not present useful content immediately. This problem could be solved by delaying the registration processes and the acceptance of the terms and conditions, thus allowing the user to navigate through the app first.

Conclusion and future work

The huge increase in smartphones and mobile devices, and the increment in users' knowledge and awareness of health information signify that mPHRs still have a promising future in health technology. Although more potent mobile devices may support more and more powerful functionalities in mPHRs, usability will be one of the biggest adoption barriers. Developers could overcome this issue by following the official usability guidelines proposed by the OS. This paper has analyzed and assessed the usability of 24 mPHRs for Android and iOS systems. A questionnaire contanining 13 assessment questions divided into 3 blocks, and inspired by the official design and usability guidelines of iOS and Android, was used. Although our results show that the iOS apps achieved a higher average score (73 %) than the Android apps (61 %), no statistical differences were found between the two platforms. The higher average score in iOS apps can be justified by the fact that Apple carries out a revision process before uploading any app. This may motivate developers to build higher quality apps.

Our findings conclude that usability is an aspect that should be significantly improved in current mPHRs. Awareness efforts and training courses for developers should be considered in academic programs for the purpose of usability in mobile applications. The questionnaire developed for the purpose of this research may also be of use to future mPHR developers in order to benchmark their product as regards usability.

As future work, we plan to extend the usability evaluation to other mobile operating systems such as Blackberry or Windows, and to apply other official usability guidelines and not only those of Android and iOS systems. Another goal of our future series of studies is to validate the results obtained by a higher sample of real users and to carry out the usability evaluation of non-free mPHRs. Lastly, we are interested in creating a reusable requirements catalog [79] based on the contents of usability documents. A requirements catalog can be adapted, refined and expressed in the form of software and system requirements and can be used as a source of useful reusable information for software development or audit activities. In order to illustrate the viability of the proposal, a security and privacy best practices catalog [80] and an audit method [81] have already been proposed in e-learning and e-health domains.

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

Appendix

Table 8 Excluded apps

Application Name	OS	Developer	URL	EC met
ADVantis PHR	and	Advantage Health Solutions, Inc.	http://goo.gl/dsf8zK	2
ADVantis PHR	iOS	Advantage Health Solutions, Inc.	http://goo.gl/DnXiIm	2
Avicenna	iOS	Not available	http://goo.gl/sMN1Qt	1
Health Companion	and	Health Companion, Inc.	http://goo.gl/NypTwr	1
MHA Mobile	and	Infogosoft AB	http://goo.gl/PkSdxu	1
miPHR	iOS	iPatientCare, Inc.	http://goo.gl/COmNq2	2
My Health Diary	iOS	NeedStreet	http://goo.gl/4zYYQG	1
MyHealth OTG	and	Cyber Development	http://goo.gl/XdMnmg	2
Personal Healthcare Record-PHR	and	Thareb Alhayat	http://goo.gl/stIWz3	1
Thareb Alhayat PHR	iOS	Ahmed Almutairi	http://goo.gl/fGr4RM	1
TheHealthNet	and	lhrArzt24 GmbH	http://goo.gl/Uzs5gy	1

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