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Usability Heuristics for Evaluating Health-care Applications for Smartphones: A Systematic Literature Review

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Abstract

Mobile devices, especially smartphones, are playing an increasing role in healthcare, enabling the delivery of complex m-health applications that allow the on-the-go care to patients wherever they are and whatever their circumstances. There exists a large diversity of m-health applications ranging, for example, from the management of chronic illnesses to the remote analysis of teleradiology examinations. M-health applications can improve quality and efficiency and provide cost savings of healthcare to a large percentage of the population. However, considering that the usage of these applications impacts on the health of humans, it is imperative to prevent usage errors, which may compromise patient safety. Thus, an important quality of such applications is usability. A way to conceptualize usability are heuristics for designing interfaces. There are various sets of usability heuristics available that have originally been developed for graphical user interfaces on desktop computers as well as diverse customizations for specific devices and/or types of applications. In this context this article analyzes the state of the art of usability heuristics specifically targeted to evaluate m-health applications on smartphones. In order to answer this question, a systematic literature review has been conducted. As result, we found only a very small number of articles reporting heuristic evaluations of this type of application. Most of these used “traditional” sets of usability heuristics. Only two articles report the usage of heuristics customized to mobile applications but not further taking into consideration specific characteristics of healthcare applications. This clearly points out the lack of research on the customization of usability heuristics for this specific kind of application, which could significantly contribute to the adoption of lightweight evaluation techniques and, thus, contributing to the improvement of the usability of m-health applications.

Keywords: usability – heuristic evaluation – m-health - smartphone - healthcare.

1. Introduction

The use of mobile devices such as smartphones is revolutionizing the way we communicate and interact. Smartphones offer a great level of computability and connectivity combining functionality from diverse devices (such as pagers, phones and PDA's), which allows them to provide new types of services and applications [1]. In this respect, smartphones are also becoming very popular among healthcare professionals as well as the general public. [2]This advance created the opportunity for the development of mobile healthcare applications (also called m-health [3]) that allow the on-the-go health care practice to patients wherever they are and whatever their circumstances. There exists a large diversity of m-health applications ranging from disease diagnosis, drug reference to medical calculator applications [2]. Many apps are also developed to support the management of chronic illnesses such as diabetes [4] [5], cancer [6] or heart diseases [7] that, for example, allow patients to measure blood pressure or remind them to take medications.

In this way, m-health can improve healthcare efficiency and provide cost savings, e.g. by monitoring patients remotely [8], reducing the need for routine office visits especially for those living in rural areas. Furthermore, they can help to ensure treatment compliance, and provide patients with tailored information. Providing such information through smartphones allows to reach a larger percentage of the population, including ones who may have no access to other IT devices. For health professionals, m-health promises expedition of daily tasks and access to information while dealing with patients, e.g. from previous check-ups, facilitating physician mobility. Especially in emergency situations, mobile devices, for example, enable neurologists to access to radiological images of stroke patients from remote sites in the context of a telemedicine evaluation [9] or the remote diagnosis of electrocardiograms by cardiologists [10] as low-cost procedures with a high potential to save lives. Thus, by removing geographical and temporal boundaries, m-health has the potential to improve the efficiency of healthcare delivery, ultimately making healthcare more effective [11][12][13].

Considering that the usage of these applications impacts on the health of humans, it is imperative to prevent usage errors, which may compromise patient safety leading to injury or even death [14]. Especially as many health systems have user interfaces so poorly designed and difficult to use that they invite a variety of human errors [15], [16], [17], [18] representing one of the single greatest threats to patient safety [14]. Current research indicates a number of usability issues with m-health apps, including small text, poor color contrast and scrolling wheels, especially for older adults [19]. Other problems are related to unclear wording or complex navigation [20]. Many health apps also do not provide adequate support for the tasks and workflow of healthcare professionals [20], which can lead them to spending unnecessary time and/or making the wrong decisions and, consequently, increase patient safety risks.

Therefore, it is important to design and target m-health apps to end-users' needs making them more efficient and easier to use while minimizing the likelihood of error [14]. This becomes even more important when considering that m-health applications are often used by the patients themselves or healthcare professionals without further IT training [22], [23], [2]. Moreover, m-health is not only used by the younger more tech-savvy generations but a large range of users (about 30%) are elderly people who wish to continue living independently in their homes being remotely monitored by health care professionals and family using mobile phones [24], [25].

In this usage context of m-health applications, it is imperative to focus on usability [26]. Usability is defined as "the measure by which a product can be used by specific users in order to achieve specific objectives with effectiveness, efficiency and satisfaction in the specific use context" [27]. A way to conceptualize usability is in terms of general principles or heuristics for designing interfaces [28], such as, for example, the heuristic "visibility of system status" expressing that the system should always keep users informed about what is going on. Usa-

bility heuristics are derived from a mix of theory-based knowledge, experience and common sense. They are typically refined into design guidelines in style guides, which in a more detailed prescriptive manner specify exactly how to design an actual interface (for example, on how to design a particular icon) or serve as a checkpoint to evaluate the compliance of an interface design in order to identify potential usability problems. Usability heuristics, therefore, are intended to help designers to develop and improve the design as well as to provide a basis for evaluating prototypes and existing systems [28]. In particular, they provide a framework for heuristic evaluation [29], a lightweight usability inspection method for finding usability problems at any point during the development process requiring little time and human resources.

There are various sets of usability heuristics available that have originally been developed for graphical user interfaces on desktop computers. Among the most popular ones are Nielsen's ten heuristics [30], Shneiderman's eight golden rules [31] or the ergonomic criteria defined by Scapien and Bastien [32]. However, these generic heuristics sets typically need to be customized to be applied for specific kind of systems (such as, for example, websites [33], e-commerce [34], e-learning [35]), or devices (e.g., interactive digital TV [36] or large screen information exhibits [37]) in order to effectively evaluate the interface design [38]. These examples illustrate that usability heuristics must be carefully selected so they reflect the specific interface being designed [38] and may require alternative heuristics or re-interpretation of existing ones in order for each heuristic to make sense.

However, taking into consideration specific characteristics and needs of m-health applications due to the healthcare context as well as the specific characteristics of mobile phones, assumptions about user interactions known from "traditional" computer usage may not hold true for mobile devices [39], [40] and/or healthcare applications 20. Clearly, the size and portability requirements of mobile phones present limitations as well as the awkward ways for data input [39]. And, although touch screen capabilities may facilitate certain actions, they also pose new challenges through the lack of tactile feedback, touch key size, etc. [42]. Mobile phones also change traditional interaction models based on the familiar WIMP (Windows, Icons, Menus, Pointer) interface style to interaction that may involve voice, gesture, sensors and location data [39].

On the other hand, specific characteristics of health care applications also may require a tailoring of usability heuristics. For example, interfaces of clinical laboratory systems may require that for the proper management of the laboratory workflow the time of critical activities is always and easily visible to the user [43] [44] or the usage of an adequate medical vocabulary (e.g., based on SNOMED (Systematized Nomenclature of Medicine)) [44] [45].

In this context, emerges the question: Do specific usability heuristics exist to evaluate mobile health applications for smartphones? In order to answer this question, this article presents the state of art based on the results of a systematic literature review.

2. Systematic Literature Review

With the objective to investigate and synthesize existing literature related to usability heuristics for healthcare applications on smartphones a group of researchers of the GQS - Software Quality Group at the Federal University of Santa Catarina in Brazil conducted a systematic literature review (SLR). We followed the procedure for performing SLR proposed by Kitchenham [46], focusing on the research question: Which sets of usability heuristics exist specifically designed for smartphone healthcare applications? As part of this study, we also compared the encountered set of heuristics to identify their differences and similarities.

2.1 Definition of the systematic literature review

In this context, our primary goal is to identify usability heuristic sets used/proposed/adapted to evaluate healthcare applications for smartphones.

Inclusion and exclusion criteria

We examined English-language articles published between 2007 and 2014. The time limitation was established due to the significant resource and technology changes since the launch of the iPhone in 2007 as the "first smartphone that had mass appeal to the general community" [47]. We limited the articles to peer reviewed work, including only papers or articles published in journals or conference proceedings.
We included any kind of article that mentioned a heuristic evaluation of a mobile health application, whenever it used an existing heuristic usability set or proposed a new set of usability heuristics specific for m-health apps.
On the other hand, we excluded:

- Any kind of article not focusing on applications for healthcare.
- Any kind of article not focusing on smartphones (e.g., desktop computers, medical devices, tablets, TVs).
- Any kind of article that neither proposes a set of usability heuristics for healthcare apps nor reports heuristic evaluations of healthcare apps (e.g., usability testing).
- Any kind of article prescribing design guidelines and/or style guides not representing usability heuristics.

Data sources and search strategy

We analyzed articles available online in relevant databases in the field of computer science and medicine: IEEE Xplore, ACM Digital Library, ScienceDirect (Elsevier), Wiley Online Library, MEDLINE/PubMed and SpringerLink. In addition, we also searched on Google Scholar in order to assure a broad coverage. The search has been limited to articles accessible via Portal CAPES[1].
With the aim to ensure that all relevant articles were considered in this study, we performed trial searches in order to calibrate the final search string. We also included several terms are used as synonyms. For instance, the term "smartphone" has been represented also by the terms "mobile", "touchscreen phones" and "handheld devices". We also used the terms "health", "e-health", "m-health" and "medical" as they are often used as synonyms. Table 1 shows the specific search strings used in each of the repositories.

[1] A portal for access to scientific knowledge worldwide, managed by the Brazilian Ministry on Education for authorized institutions, including universities, government agencies and private companies (www.periodicos.capes.gov.br).

Table 1: Search strings for each repository

Repository	Search String
IEEE Xplore	((mobile OR smartphones OR "handheld devices" OR "touchscreen devices" OR "touchscreen mobile devices" OR "touchscreen phones") AND (telemedicine OR health OR healthcare OR e-health OR m-health OR ehealth OR mhealth OR "clinical laboratory system" OR telehealth OR medical) AND ("heuristic evaluation" OR "usability heuristics")) in Metadata & Full Text and published between 2007 and 2014.
ACM Digital Library	(mobile or smartphones or "handheld devices" or "touchscreen devices" or "touchscreen mobile devices" or "touchscreen phones") and (telemedicine or health or healthcare or e-health or m-health or ehealth or mhealth or "clinical laboratory system" or telehealth or medical) and ("heuristic evaluation" or "usability heuristics") for: ((mobile or smartphones or "handheld devices" or "touchscreen devices" or "touchscreen mobile devices" or "touchscreen phones") and (telemedicine or health or healthcare or e-health or m-health or ehealth or mhealth or "clinical laboratory system" or telehealth or medical) and ("heuristic evaluation" or "usability heuristics")) and (PublishedAs:journal OR PublishedAs:proceeding)
ScienceDirect	pub-date > 2007 and [mobile or smartphones or "handheld devices" or "touchscreen devices" or "touchscreen mobile devices" or "touchscreen phones" and telemedicine or health or healthcare or e-health or m-health or ehealth or mhealth or "clinical laboratory system" or telehealth or medical and ["heuristic evaluation" or "usability heuristics"].
Wiley Online Library	mobile or smartphones or "handheld devices" or "touchscreen devices" or "touchscreen mobile devices" or "touchscreen phones" in All Fields AND telemedicine or health or healthcare or e-health or m-health or ehealth or mhealth or "clinical laboratory system" or telehealth or medical in All Fields AND "heuristic evaluation" or "usability heuristics" in All Fields between years 2007 and 2014
MEDLINE/ Pubmed	((mobile OR smartphones OR "handheld devices" OR "touchscreen devices" OR "touchscreen mobile devices" OR "touchscreen phones") AND (telemedicine OR health OR healthcare OR e-health OR m-health OR ehealth OR mhealth OR "clinical laboratory system" OR telehealth OR medical) AND ("heuristic evaluation" OR "usability heuristics")) Publication dates from 2007/01/01 to 2014/06/05)
SpringerLink	'(mobile OR smartphones OR "handheld devices" OR "touchscreen devices" OR "touchscreen mobile devices" OR "touchscreen phones") AND (telemedicine OR health OR healthcare OR e-health OR m-health OR ehealth OR mhealth OR "clinical laboratory system" OR telehealth OR medical) AND ("heuristic evaluation" OR "usability heuristics")' within 2007-2014
Google Scholar	((mobile OR smartphones OR "handheld devices" OR "touchscreen mobile devices" OR "touchscreen phones")AND(telemedicine OR "health care" OR ehealth OR mhealth OR "clinical laboratory system" OR medical)AND("heuristic evaluation" OR "usability heuristics")) published between 2007 and 2014. (mobile OR smartphones OR "handheld devices" OR "touchscreen devices" OR "touchscreen mobile devices" OR "touchscreen phones") AND (telemedicine OR health OR healthcare OR e-health OR m-health OR ehealth OR mhealth OR "clinical laboratory system") published between 2007 and 2014.

2.2 Search Execution

The search was performed between April and May 2014 by researchers of the Software Quality Group, including professors, graduate and undergraduate students with background in the areas of computing, design and telemedicine. Searching the databases as defined,

several potentially relevant articles have been returned. Table 2 indicates the number of search results per repository.

Table 2. Number of search results

Repository	Number of search results
IEEE Xplore	114
ACM Digital Library	842
ScienceDirect	42
Wiley Online Library	25
MEDLINE	6
SpringerLink	222
Google Scholar	2170

The 400 most relevant results (or less) returned by each database have been reviewed based on their title, abstract and keywords, selecting those potentially pertinent applying the defined inclusion and exclusion criteria. This has been done initially individually by each of the researchers and then discussed until consensus has been achieved. As an intermediate result, 28 articles were selected. Then, we further analyzed these in detail based on the complete article. We observed that some of them either focus on different devices, do not apply heuristics for usability evaluations or do not propose specific heuristics for healthcare applications. Many of them also rather focus on concrete design guidelines and style guides or addressed usability in other contexts not related to the software interface of mobile applications, and, therefore, they were discarded. After this step, 7 articles have been considered relevant within the focus of our review.

2.3 Data Extraction

From the articles, relevant data with respect to our research question has been extracted. This includes:

- the title and reference of the article;
- reference of the set of heuristics used in the research;
- the indication on if the article describes the development of a set of heuristics, its application or the adaptation of an existing set;
- the type of m-health application being evaluated classified according to its purpose. For classification we follow the definition given by [48] indicating 39 different categories, including, e.g., emergency assistance, education, health diary, medical tools or pharmacy services;
- a short description of the mobile application being evaluated;
- the mobile platform of the application on which the heuristic evaluation has been performed, and
- the type of user defined according to [2], including healthcare professionals, medical or nursing students, or patients.

This again has been done first by all co-authors individually and then discussed until consensus has been reached. The extracted information is presented in Table 3.

Table 3. Extracted Information

Nº	Title/Reference	Set of Heuristics	Heuristics developed\ applied\ adapted	Type of Application	App evaluated	Platform	Type of User
01	A Usability Study of a Mobile Health Application for Rural Ghanaian Midwives / [49]	Bertini, 2006 [50]	Applied	Obstetrics and Gynecology	mClinic, a mobile health application to support midwife access to the Millennium Village-Global Network, an eHealth delivery platform that captures data for managing patient care.	Android	Healthcare professional
02	Systematic Analysis of Mobile Diabetes Management Applications on Different Platforms / [51]	Bertini, 2009 [40]	Applied	Health Diary	Set of 15 different diabetes management applications based on user's data entry.	Android, Blackberry and iOS	Patient
03	Need for Usability and Wish for Mobility: Case Study of Client End Applications for Primary Healthcare Providers in Croatia / [52]	Nielsen, 2004 [30]	Applied	Others (health care information system/HER)	Client end application used by PHC Providers (Nurse, Pediatrician, Gynecologist) to access Primary Health-Care Information System.	Paper prototype	Healthcare professional
04	MANTRA: Mobile Anticoagulant Therapy Management / [53]	Nielsen, 2004 [30]	Applied	Therapy	Applications for management of anticoagulation therapy through the results of INR (International Normalization Ratio) monitors.	Android/ iOS	Patient
05	An Electronic Health Care - Cardiac Monitoring System / [54]	Nielsen, 1992 [55]; Dunlop & Brewster, 2002 [56];	Applied / Adaptation of Nielsen's Heuristics and Dunlop & Brewster	Cardiology	Electrocardiogram monitoring application that gathers the results of Bluetooth-enabled ECG sensors.	Windows Mobile	Healthcare professional

06	Usability and Feasibility of PmEB: A Mobile Phone Application for Monitoring Real Time Caloric Balance / [57]	Nielsen, 2004 [30]	Applied	Health Diary	An application that monitors the user's daily calorie consume.	Functional Prototype	Patient
07	A health literacy and usability heuristic evaluation of a mobile consumer health application / [58]	Monkman, 2013 [58]	Developed	Reference[2]	Reference guide application for the comprehension of blood test reports.	iOs	Patient

The results show that heuristic usability evaluations of m-health apps are reported for both patients and healthcare professionals use. The purpose of the applications is diverse just as reported by [2]. Among the evaluations reported for patient's use, two are related to the self-management of illnesses such as diabetes (article 2) and thrombosis (article 4), one was developed for the control of the user's caloric intake (article 6), and the other one is a reference guide for everyone to understand blood test reports (article 7). Regarding the use of healthcare professionals, all three apps were developed for the monitoring of patients' health (articles 1, 3, 5).

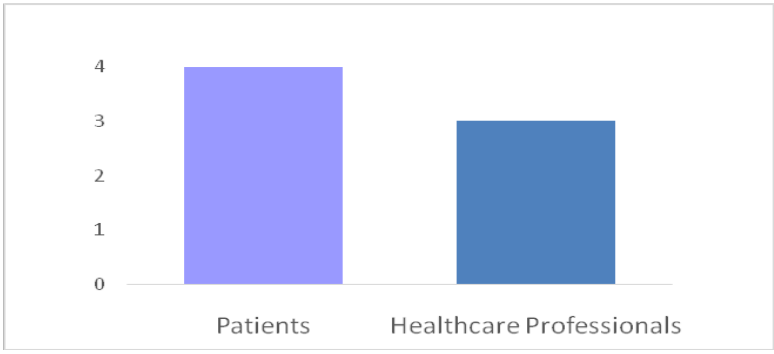

Figure 1. Number of evaluated applications classified by user category

The seven applications for which evaluations have been reported were classified according to their healthcare purpose: two of them are health diary applications, one is developed to be used by cardiologists and one is an obstetrics and gynecology application. We also encountered evaluations of a therapy application and a reference application, developed for users with little or no knowledge on the interpretation of blood test reports. One app provides access for healthcare professionals to the patient's information in a centralized way as a kind of electronic health record (EHR) via smartphones.

Most evaluations reported have been done with applications running on iOS or Android phones, which corresponds to the general predominance of these two mobile platforms [59]. A small number of heuristic evaluations were also found for others platforms such as Windows Mobile and Blackberry OS (Figure 2). Two evaluations were applied to prototypes, one using a paper prototype (visualizing aspects and features of the applications) and the other

[2] The apps classified as Reference, are supposed to be used by healthcare professional, but this guide is meant to be used by patients.

using a functional prototype (an executable code representation very close to the final product).

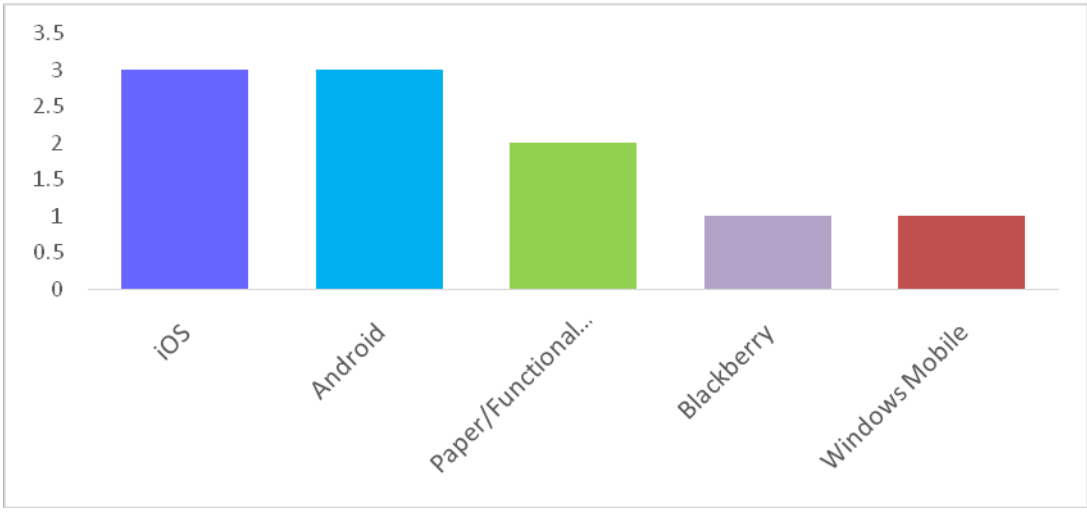

Figure 2. Number of heuristic evaluations by platform

Different sets of heuristics have been used in the reported evaluations. Table 4 presents an overview on the four sets of heuristics that have been used.

Table 4. Summary of the developed/adapted/applied sets of heuristics

Reference	Nielsen (1994 [30],1995 [60])	Bertini et al. (2006 [50], 2009 [40])	Monkman (2013) [58]	Nielsen + Dunlop and Brewster (2010) [54]
Heuristics	1. Visibility of system status 2. Match between system and the real world 3. User control and freedom 4. Consistency and standards 5. Error prevention 6. Recognition rather than recall 7. Flexibility and efficiency of use 8. Aesthetic and minimalist design 9. Help users recognize, diagnose, and recover from errors 10. Help and documentation	1. Visibility of system status and losability/findability of the device 2. Match between system and the real world 3. Consistency and mapping 4. Good ergonomics and minimalist design 5. Ease of input, screen readability and glancability 6. Flexibility, efficiency of use and personalization 7. Aesthetic, privacy and social conventions 8.Realistic error management	1. Have a simple and engaging home screen 2. Make registration and logging in as simple and obvious as possible 3. Put the most important information first 4. Tell users what to do and how to do it 5. Stay positive and realistic. Include the benefits of taking action 6. Provide specific action steps 7. Write in plain language 8. Check content for accuracy 9. Display content clearly on the page 10. Include a limited amount of interactive content that users can tailor 11. Use meaningful headings 12. Ensure styles are consistent 13. Ensure the font is easy	1. System feedback and reasonable response time 2. System spoke users language avoiding "system terms" 3. System allows 'Easy escape / Exit" 4. Consistent user interface using standard phrases and commands 5. Understandable error messages 6. Interface is aesthetic and minimalistic 7. Streamlined feature set, allowing easy screen browsing 8. Support system, available help at all times

			to read 14. Use white space and avoid clutter 15. Keep content in the center of the screen and above the fold 16. Use images that facilitate learning 17. Use bold colors with contrast and avoid dark or busy backgrounds 18. Make the system accessible to people with disabilities 19. Put topics in multiple categories 20. Enable easy access to home and menu screens 21. Make sure the “Back” button works 22. Use linear information paths (e.g., numbered screens) 23. Simplify screen-based controls and enlarge buttons 24. Label links clearly and use them effectively 25. Include simple search and browse options 26. Invite users to share content and provide feedback about their experiences 27. Include printer-friendly tools and resources 28. Incorporate audio and visual features 29. Explore new media such as Twitter or text messaging	9. Recognition rather than recall 10. System presentation and ease of relative tasks
Articles that used these heuristics	03, 04, 06,	01, 02	07	05

3. Discussion

Despite the recognition of the importance of usability for the ever-increasing number of m-health applications, our review showed that so far researches focusing on usability heuristics and evaluations of m-health apps are still sparse. Finding only seven articles with this focus, demonstrates clearly a lack of research in this area.
When analyzing the heuristics used for evaluations of m-health applications, we can observer a clear predominance of the traditional set of Nielsen’s 10 heuristics (Figure 3).

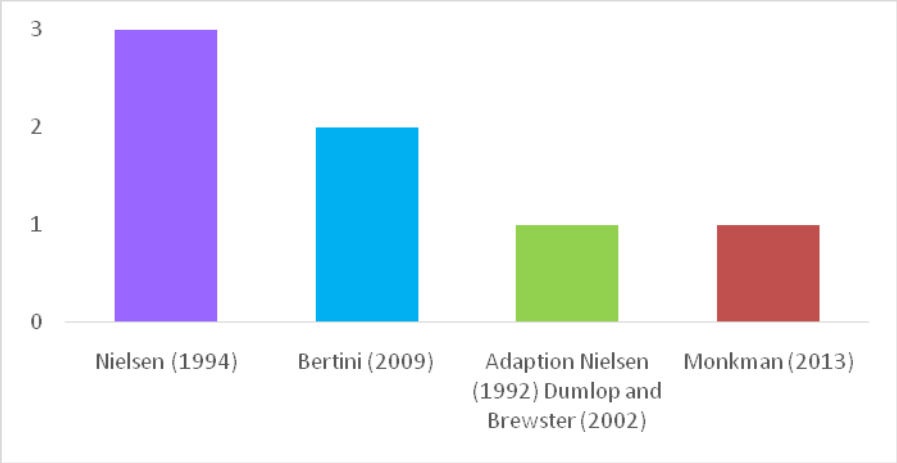

Figure 3. Number of evaluations per set of heuristics

This shows that traditional heuristics (originally developed for desktop applications) are still used to evaluate mobile applications. Different from our expectation, most studies did not use specifically customized heuristics neither with respect to mobile nor to healthcare characteristics to perform the evaluations. Instead, they simply used traditional heuristics including Nielsen ([52] [53] [54] and [57]) and an empirical adaption and unification of the sets by Dunlop & Brewster and Nielsen ([54]). This leads to the question, if, thus, a customization may not be necessary? Several articles do not justify the selection of the set of heuristics. Only Kukec et al. (2011), explains the use of Nielsen's heuristics assuming that it covers all of the significant aspects of usability by comprising guidelines for user interface design in such a general way that they also cover specific issues associated to mobile apps.

However, another hypothesis of why the majority simply used "traditional" sets of heuristics may be the lack of well customized and validated sets for this specific context. Two articles [49] and [51] in fact report the usage of heuristics customized for mobile apps, as proposed by Bertini [40]. Bertini customizes a set of usability heuristics set based on a literature review with the objective to include relevant aspects of mobile cell phone applications, including, for example, the heuristic "Ease of input, screen readability and glancability". This heuristic reinforces that mobile users must be allowed to input data and scanning the screen as efficiently as possible, besides the difficulties imposed by the device limitations. This set was validated confronting the results of heuristic evaluations using the proposed set against the results of heuristic evaluations using Nielsen's heuristics [60]. The results showed that the set customized to mobile apps produced a more accurate evaluation in terms of number of problems detected. This set however, customizes heuristics to mobile applications in general, not taking into consideration specific characteristics of healthcare applications.

The only set of heuristics encountered customized to identify usability problems of m-health applications was proposed by Monkman [58]. By modifying guidelines proposed by Health Literacy Online (HLO) [61] , the author proposes a set of 29 heuristics (such as "Check content for accuracy" and "Incorporate audio and visual features"), divided into 5 categories (screens, content, display, navigation, and interactivity). This set was validated by confronting the results of heuristic evaluations using the proposed set with evaluations based on guidelines proposed by HLO [61]. The comparison showed that, although the majority of the recommendations from the HLO guide for web sites were applicable for assessing mobile usability, the heuristics generated in the study benefit from being complemented with other evidence-based heuristics specific to mobile devices. So far, this set has only be used in an evaluation by the author himself [58].

Analyzing in more detail the heuristics used, we can observe a certain coherence among them due to the recurrence of traditional heuristics. The heuristics "Visibility of system sta-

tus", "Consistency and standards" and "Help users recognize, diagnose, and recover from errors" were used in three sets. Other heuristics also are recurrent, only under different names, such as "Match between system and the real world". This heuristic appeared in four sets and/or concentrated its focus to a specific issue within the heuristic, such as focusing on a match of the language used ("System spoke users language avoiding system terms" (Nielsen + Dunlop and Brewster, [54]) or "Write in plain language" [58]). Similarly, the heuristic "Aesthetic and minimalist design" appeared in 3 sets, called "Good ergonomics and minimalist design" by Bertini [40] and "Interface is aesthetic and minimalist" by the adapted set Nielsen + Dunlop and Brewster [54].

The observed recurrence of traditional heuristics may in fact indicate that these traditional heuristics are suffiently generic to cover usability issues independently of the type of device and or application. These results are also confirmed by other reviews focusing e.g. on mobile applications in general [62]. Yet, it also seems that only the traditional heuristics are not sufficient to cover comprehensively specific characteristics of different types of devices and/or application. So typically, these sets are customized by adding new specific heuristics. Examples with respect to the customization for mobile applications include heuristics "Ease of input, screen readability and glancability", "Aesthetic, privacy and social conventions" as added by Bertini et al. [40] or "Streamlined feature set, allowing easy screen browsing" by Nielsen + Dunlop&Brewster [54]. In a similar way, Monkman [58] added the following heuristics: "Have a simple and engaging home screen", "Put the most important information first", "Include a limited amount of interactive content that users can tailor", "Simplify screen-based controls and enlarge buttons", "Label links clearly and use them effectively" and "Include simple search and browse options". All these added heuristics are related to specific characteristics of mobile devices, such as limited screen size, in order to facilitate data entry and reading on screen. The developers are also encourage to "Incorporate audio and visual features" both to get the user's attention and to give feedback.

However, we could not detect any specific heuristic added with respect to specific characteristics of healthcare applications. Such a lack of customization has also been reported by others [63] [64]. Yet, general research in the healthcare sector (not focusing exclusively on heuristic evaluations and/or mobile phones) indicate such a need for customization. Examples include the work on the customization of heuristics for clinical laboratory systems [44], Electronic Health Record systems [65] [43][66] (both for the usage on desktop computers) or medical devices (Using usability heuristics to evaluate patient safety of medical devices [15]) as well as adaptations of usability testing for m-health applications [41].

Threats to validity

The validity of a study denotes the trustworthiness of the results and to what extent the results are true and not biased by the researchers' subjective point of view [67]. As with all research, there exist several threats to the validity of the results presented. However, in order to minimize potential threats we carefully followed a systematic literature review process as proposed by [46]. In order to prevent the unintentional exclusion of any important work in this area, we constructed the search string to be as inclusive as possible focusing on our research question. However, a limitation of the current search string lies in the exclusion of stand-alone terms such as "evaluation" and "heuristics". These individual terms lead to a large number of search results that are mostly irrelevant by considering evaluation and heuristics in a way not related to usability. To mitigate the risk of excluding potential relevant primary studies, a search string containing qualifiers to those terms (e.g. "usability heuristics" and "heuristic evaluation") was constructed, including also several synonyms. We also included in the string the term "e-health" with the intention to not overlook articles that might have used this term to refer to "m-health". We conducted the search using several prominent databases, covering the majority of scientific publications in the field of computing and medicine, as well as informal searches in parallel in order to reduce the risk of excluding relevant studies.

The threat presented in the extraction and/or analysis and interpretation of data was mitigated with the involvement of junior and senior researchers with computing and design background and practical experience in the design of mobile applications interfaces throughout the process. All work was conducted by the authors together, constantly reviewing and discussing the data and results to reach a consensus.

4. Conclusion

In this article we present the results of a systematic literature review to analyze the existence of specific usability heuristics for m-health applications. As result, we found only a very small number of articles reporting heuristic evaluations of this type of application. Most of these used “traditional” sets of usability heuristics, originally developed for any kind of application on desktop computers. Only two articles report the usage of heuristics customized to mobile applications but not further taking into consideration specific characteristics of healthcare applications. But, due to the enormous potential and currently advancing market of m-health applications and the importance of usability for their large-scale adoption and the minimization of patient’s safety risks, there clearly seems to be lack of research on the customization of usability heuristics for this specific kind of application on smartphones. Providing a specialized set of heuristics for m-health could significantly contribute to the adoption of lightweight evaluation techniques as part of the usability engineering process that can be applied quickly and with minimal effort and, thus, contributing to the improvement of the usability of m-health applications.

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