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Mapping HCI Principles to Design Quality of Mobile User Interfaces in Healthcare Applications

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Abstract

This paper reports on research carried out in the field of Human-Computer Interaction (HCI) on the interaction between a human and a mobile device, in the specific case where a healthcare professional uses the mobile device to access a medical application. The quality of mobile user interface is crucial in the healthcare domain, as the attention of healthcare professionals is usually on the patient and not on the system, and so low-quality UIs may lead to critical medical errors. In this research, the quality-in-use measurement model (QiU-4-MUI) is used to empirically investigate the impact of HCI principles on the quality of an MUI, in terms of five important characteristics, namely, effectiveness, productivity, efficiency, error safety, and cognitive load. The work investigates the applicability of these quality characteristics as indicators of the impact on user interface design of HCI principles, such as mental model, metaphor, feedback, affordance, and visibility. A controlled experiment was carried out among 23 doctors in a hospital environment to empirically investigate the impact of HCI principles on the quality in use of a mobile user interface, in terms of the QiU-4-MUI characteristics and in the healthcare context.

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Keywords: Healthcare applications; Human computer interaction principles; Quality-in-use measurement model; Mobile user interfaces; Controlled expeiment;

1. Introduction

Today's smartphones are powerful computers combined with the well-known features of a telephone. So, there has been a great deal of interest in the use of mobile applications to support healthcare and healthcare practitioners. According to industry estimates, by 2018, 50 percent of the more than 3.4 billion smartphone and tablet users will have downloaded mobile health applications[1].

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These users include healthcare professionals, consumers, and patients. In the United States, the food and drug administration (FDA) is encouraging the development of mobile medical applications that improve healthcare, and provide consumers and healthcare professionals with valuable health information[2].

As these increasingly sophisticated mobile devices are now mass-market commodities, careful consideration must be given to smartphones and their apps, in terms of their aesthetics, usability, and utility, as well as the emotional aspects of the user experience[3]. Novices need an interface that is easy to master and easy to use[4].

Simplicity is the most important principle of interface design[5]. To achieve simplicity, the mobile user interface (MUI) design has to be consistent, and avoid cognitive overload and disorientation in the user.

Our aim in this research is to explore the impact of Human-Computer Interaction (HCI) principles on the quality in use of the MUI design for medical mobile applications.

It is important to point out that the research reported and summarized in this paper builds on our previous work[6], which focused on the design of a desktop UI in the healthcare domain based on HCI principles. Our current research, also carried out in this domain, moves into the area of MUI design, focusing on human-mobile interaction in the context of healthcare applications.

In this research, the quality-in-use measurement model (QiU-4-MUI) [7] is used to empirically investigate the impact of HCI principles on the quality of an MUI, in terms of increasing the user's effectiveness, productivity, efficiency, error safety, and of improving task navigation by reducing the cognitive load.

The method of research used in this work is a controlled experiment. A controlled experiment was carried out among 23 doctors using the Phoenix Health Information System (PHIS) application currently installed at King Abdulaziz University Hospital (KAUH). The empirical investigation confirmed the positive impact of the HCI principles Mental Model, Metaphor, Visibility, Affordance, and Feedback on an MUI design in terms of the QiU-4-MUI model's quality-in-use characteristics.

The rest of the paper is organized as follows: Research motivation and related work on designing medical apps based on HCI principles is reviewed in section 2. In section 3, the HCI principles required to understand this paper are introduced, and the connection between them and the QiU-4-MUI measurement model is explained. The MUI design guidelines inspired by the HCI principles are presented in section 4. The experimental design and the results are described in section 5. The findings are discussed in section 6. Finally our conclusions and directions for future work are presented in section 7.

2. Research Motivation and Related Work

As the technological sophistication of mobile devices has grown, the UIs of mobile apps are becoming increasingly complex. Consequently, the MUI design must be both usable and useful, and it must be user-centered.

Most researchers in HCI are interested in developing new design methodologies, experimenting with new hardware devices, prototyping new software systems, and exploring new interaction paradigms[8]. Also, users' preferences change as they gradually master new interfaces[9]. A study by Localytics estimates that 22 percent of downloaded apps are only opened once; the most common reason for applications not being used is their failure to base MUI designs on HCI principles[10].

The process of adopting HCI principles in designing MUIs and applying them in the healthcare domain has been explored in a limited number of projects. In[11] the authors show that some healthcare devices fall far short of expectations, indicating that HCI principles may not have been fully adhered to. The authors of [11] explore the hardware design problems and make recommendations for redesigning the control panel of a hospital bed based on HCI principles. Buranatrived et al. conduct an empirical study of the effect of device type by comparing the performance of the same J2ME application running on a PDA and a smartphone[12].

In the research report in this paper, the QiU-4-MUI measurement model is used to empirically investigate the impact of the HCI principles on the MUI design's quality-in-use characteristics[13]. The link between the QiU-4-MUI quality characteristics and HCI principles such as mental model, metaphor, feedback, affordance, and visibility is described next.

3. Mapping HCI principles to MUI design quality characteristics

Quality-in-use is "the degree to which a product or system can be used by specific users to meet their needs to achieve specific goals with effectiveness, efficiency and satisfaction and reduced risk in specific contexts of use" [14]. Our QiU-4-MUI quality characteristics are based on the ISO 25010 international standard definition of quality-in-use[15]. Our approach is to match the QiU-4-MUI quality characteristics to HCI principles specifically adapted to the type of UI used in the healthcare domain. The QiU-4-MUI quality characteristics definitions and interpretations are defined in Table-1[16].

Table 1. Quality characteristics of the QiU-4-MUI model

Quality-in-use characteristics	Definition of the Objective characteristics of the QiU-4-MUI	Interpretation
Effectiveness	Number of actions required to complete the subtasks of each task in a specified context of use. It is measured in actions per task.	The closer to 1.0 the better
Productivity	Number of actions performed in a specified context of use relative to the time taken by the user to complete the task. It is measured in actions per second.	The larger the better
Efficiency	The efficiency of the user in completing the task in a specified context of use. It is measured in actions per second.	The larger the better
Error Safety	The safety of the user, in terms of the number of errors committed in each action of each task performed in a specified context of use. It is measured in errors per action.	The closer to 1.0 the better
Cognitive load	For a given user task, the weighting of each screen view by the number of actions performed on that screen, which must be minimized to keep the user focused on the task at hand, but sufficient to increase the user's confidence in using the application and to reduce the possibility of the user losing interest during a task. It is measured in number of actions per view.	The larger the better

The adherence to the HCI principles is a crucial part of designing and implementing an effective MUI. Therefore, the quality characteristics of an MUI must reflect the degree to which the MUI design conforms to the HCI principles.

In this work we examined the relationships between the effects of the fundamental HCI principles on MUI design quality (mental model, affordance, etc.) [9,17], and the QiU-4-MUI quality characteristics (effectiveness, productivity, etc.).

The remaining part of section 3 summarizes the relationships elicited in this research between the HCI principles and the QiU-4-MUI characteristics.

3.1. Mapping the HCI principle Mental Model to QiU-4-MUI characteristic Effectiveness

MUI designers must keep in mind the knowledge that a user may have from his or her experience in the real world, such as using a desktop UI, and how this may be applied to an MUI. HCI practitioners define a mental model as a set of beliefs about how a system works[18]. A mental model is powerful, because it is the lens through which we interpret the world, and we interact with any system based on these beliefs.

Applying the principle of the mental model should lead to an increase in the effectiveness of the user when using a mobile application in the context of healthcare in terms of completing the tasks with minimum number of actions.

3.2. Mapping the HCI principle Affordance to QiU-4-MUI characteristic Productivity

In HCI terms, perceived affordance is the quality that makes it easy for a user to spot and identify the functionalities that a UI offers[17].

Applying the affordance principle to the design leads to a decrease in the time taken by the user to complete the task successfully when using the MUI in the context of healthcare domain.

3.3. Mapping the HCI principle Visibility to QiU-4-MUI characteristic Efficiency

With visibility, the MUI should help the user understand the current state of the application and the operations that can be performed[9].

Applying the visibility principle leads to an increase in the efficiency of the user in completing the task using the MUI in the context of healthcare.

3.4. Mapping the HCI principle Feedback to QiU-4-MUI characteristic Error Safety

Feedback is the information that the user should receive concerning the response of the UI to any action performed. Better feedback can eliminate errors in actions performed on the MUI; for example, when an action appropriate for one type of UI is mistakenly performed on another type.

Applying the feedback principle leads to an increase in the safety of the user when using MUI in the context of healthcare and adds to the trust, in the sense that the user performs the task correctly with minimum number of incorrect actions and satisfaction.

3.5. Mapping the HCI principle Metaphor to QiU-4-MUI characteristic Cognitive Load

The metaphor principle provides the user with short-cuts to understanding difficult concepts in using the MUI, which can be used to shape user behavior in circumstances that are unfamiliar and that they might otherwise find confusing[19]. Applying the metaphor principle leads to a decrease in the cognitive load on the user when using the MUI in the context of healthcare by reducing the number of actions in each view.

All these points are important area of further research on the HCI principles' impact on the MUI design's quality. In the HCI research on MUI reported in this paper a list of guidelines specifically designed for MUIs and inspired by the HCI principles, is proposed.

Figure 1 illustrates the resulting mapping between the HCI principles and the QiU-4-MUI quality characteristics.

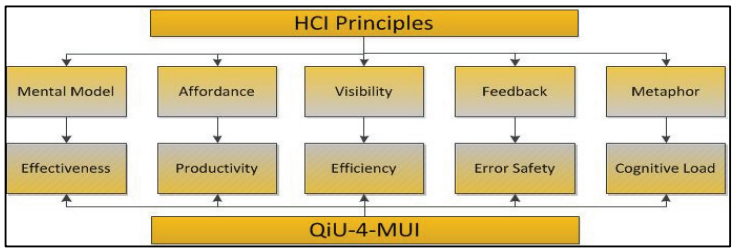

Fig. 1. Mapping of HCI principles to QiU-4-MUI

4. MUI design guidelines based on HCI principles

In this research we provide a list of guidelines for improving the quality in use of the MUI design inspired by the HCI principles. Sample of these guidelines are listed below:

4.1. Mental model

- Create three tab views, one each for Laboratory, Radiology, and Pharmacy, with a different symbol for each view to speed up information retrieval (Figure 2- A).
- Display the words that start with the same first letter in the search of a patient name, drug name, laboratory test result, or radiology test result (Figure 2- B).

- Add a Settings option to the main menu to allow the user to adjust font size and brightness level, and to select the text-to-speech option or the speech recognition option (Figure 3).

4.2. Affordance

- Avoid false or misleading affordance. For example, the medication symbol appears on a tab (Figure 2- C).
- Reduce the need for typing on the views, by providing a menu on most of the entry views to help prevent errors.
- Set an alert message to be triggered if a selection error occurs, so that the user can recover from the error immediately.

4.3. Metaphor

- On the Radiology, Laboratory, and Pharmacy views, provide options to help the user perform new order or review result tasks quickly, using familiar medical symbols for navigation purposes (Figure 2- C).
- Provide only frequently used navigation symbols, to simplify the system.

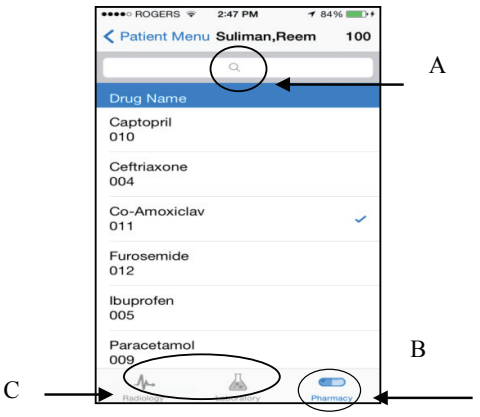

Fig. 2. Pharmacy Order view

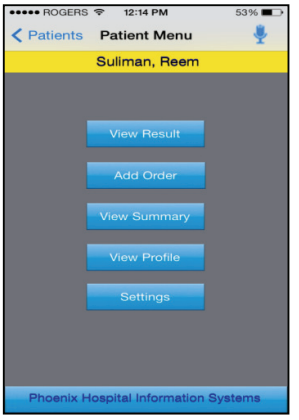

Fig. 3. Main Menu view

4.4. Visibility

- Activate a colorful tab symbol for the current view, and deactivate the other tab symbols (Figure 2- A).
- Allow the user to select the font size for the views to match his or her preferences.
- Provide a Patient Menu to give the user access to all the views related to patient care, in order to reduce the cognitive load on the users and to facilitate their access to patient data and make changes (Figure 3).

4.5. Feedback

- Provide good feedback on all the views. For example, highlight the most recent laboratory result in yellow and display it at the top of the list.
- Display the patient name and the patient's medical record number (MRN) on all the main views such as order and result view (Figure 2).
- Show the name of the main view in the middle of the window at the top such as patient menu (Figure 3).

The aim of the above listed HCI guidelines is to integrate the corresponding HCI principles into MUI design. The authors designed the MUI for the PHIS2 application on an iPhone™ smartphone (PHIS2-M), based on HCI principles. The proposed design is expected to reduce user error, and enhance quality in terms of the QiU-4-MUI

objective characteristics. The effect of designing MUI based on the proposed HCI guidelines is further investigated empirically through a carefully controlled experiment using the QiU-4-MUI model.

5. Controlled Experiment

In this section we assess the impact of the five HCI principles on the quality of MUI, by comparing them with the well-known effect of the HCI principles on desktop UI for the same application (PHIS2). The size of the experimental sample was 23 doctors. The comparison is carried on desktop UI (PHIS2-D) and mobile UI (PHIS2-M) in terms of the five quality characteristics of the QiU-4-MUI measurement model (see section 3). Pairs of hypotheses were formulated for each quality characteristic and HCI principle (Figure 1). A sample pair of hypotheses related to the effect of the HCI mental model on MUI effectiveness, is listed next:

HYP10: There is no significant difference in the impact of the HCI mental model on the effectiveness of the desktop UI design and mobile UI design.

HYP1a: There is a significant difference in the impact of the HCI mental model on the effectiveness of the desktop UI design and mobile UI design.

5.1. Conducting tests

The controlled experiment presented in this section concerns the testing of two scenarios of use of the PHIS, deployed in two different configurations and used by a group of 23 male and female doctors belong to junior stereotype[20] that is adaptable to the healthcare context[21], in order to validate the effect of UI type on the quality characteristic of the QiU-4-MUI model. The study was conducted on an iPhone™ 4.1 iOS 5.1 smartphone. The QiU-4-MUI objective measurement data was collected using PHIS2-D and PHIS2-M by expert doctors at the KAUH to identify problems they were having with the system.

The tests were conducted one participant at a time in a closed environment inside King Abdulaziz University hospital with minimum background noise, in order to determine the effect of UI type. Each participant was asked to perform a set of tasks, once using the desktop version of the application and once using the mobile version in a random way.

Prior to conducting the formal evaluation of the PHIS2-D and PHIS2-M designs, a list of materials to be used during the test, as suggested by[22], was prepared.

5.2. Data collection

Two data collection methods were used to gather information from the participants: interviews, and observation while they performed a list of tasks on PHIS2-D and PHIS2-M. With these methods, the authors evaluated the participants' ability to use the desktop- and mobile-based healthcare applications.

5.3. Results of the QiU-4-MUI Objective Quality Characteristics

The objective characteristics of the QiU-4-MUI were used as quantitative indicators of the effectiveness, productivity, efficiency, error safety, and cognitive load of the UIs of desktop and mobile apps designed based on HCI principles.

In order to investigate the statistical significance of the observed differences in the objective characteristics of the QiU-4-MUI, the raw data for the empirical study were tabulated in SPSS for each of the 23 participants. We calculated automatically the objective subcharacteristic for each task separately. Then we used the mean of all 5 tasks, for all the 23 participants, and for each characteristic to compare the QiU-4-MUI between the desktop UI and the MUI. We relied on the mean because we are 95% confident that the mean of each subcharacteristic lies within the confidence interval. Since we have two conditions (using the DUI, and using the MUI) for the same participants, the data was paired. To use the paired Student t-test[23], we checked the normality of each pair first.

Based on the experimental results of our controlled experiment we concluded the following:

HYP1. The impact of the HCI mental model principle on the quality of MUI is higher than the desktop UI, as indicated by the effectiveness characteristic.
HYP2. The impact of the HCI affordance principle on the quality of MUI is higher than the desktop UI, as indicated by the productivity characteristic.
HYP3. The impact of the HCI visibility principle on the quality of MUI is higher than the desktop UI, as indicated by the efficiency characteristic.
HYP4. The impact of the HCI feedback principle on the quality of MUI is higher than the desktop UI, as indicated by the error safety characteristic.
HYP5. The impact of the HCI metaphor principle on the quality of MUI is higher than the desktop UI, as indicated by the cognitive load characteristic.

In addition, the results of the experiment show that the benefits of designing medical mobile applications based on HCI principles for healthcare professionals include i) increased effectiveness, productivity, and efficiency through the ability to use the application anywhere and at any time; ii) increased safety, through error reduction by restricting the use of the MUI to the options available, and iii) reduced cognitive load on the user, through a reduction in the number of navigation-related actions.

6. Discussion

The results of the controlled experiment provide us with a list of lessons that prove the applying HCI guidelines to the MUI design leads to a quality-in-use increase indicated by the QiU-4-MUI characteristics in terms of:

- Effectiveness: Considering the mental model in designing the MUI leads to better control over the actions that are required to complete the task successfully by helping the user make the right decisions and take the right action. This leads to an improvement in user effectiveness.
- Productivity: Considering affordance in the design of the MUI leads to a more efficient design by suggesting the right functionality and choosing suitable icons and symbols to guide the user to select the correct action in less time. This leads to an increase in user productivity.
- Safety: Considering the feedback principle in designing MUI provides the user with evidence of closure in the form of direct manipulation interactions, which satisfies the communication expectations users have when engaging in a dialogue via the MUI, and provides confirmation that the operation is being carried out correctly. This leads to an increase in safety by reducing the number of incorrect actions.
- Efficiency: Considering the visibility principle in designing the MUI improves the way information is presented and requested from the user in a clear way, and lets the user know what is happening and what is about to happen. This leads to increased user efficiency in performing the task.
- Cognitive load: The metaphor principle describes the overall "concept" that user may use to organize all the objects and actions in the MUI into a coherent whole. Considering the right metaphor supports fast and efficient interaction for the user by reducing their cognitive load and enhancing their performance.

The results of the controlled experiment can be generalized to anyone accustomed to working with a smartphone. However, in this experiment, the controlled environment consisted of a group of healthcare professionals who have had a great deal of exposure to modern technology.

7. Conclusion and Future Work

In this research, we have assessed the impact of HCI principles on the quality of MUIs in the healthcare context, in terms of: i) increasing user safety by minimizing human error, ii) increasing the effectiveness and efficiency of the execution of the tasks carried out by doctors, iii) increasing the productivity of the doctors, and iv) reducing the cognitive load on the doctors.

The empirical investigation results confirmed that considering the HCI principles Mental Model, Metaphor, Visibility, Affordance, and Feedback in the MUI design leads to increased quality-in-use of the MUI.

The empirical evaluation of the effect of the HCI principles on the quality-in-use of PHIS2-based mobile app revealed that the app is a success in terms of helping doctors perform tasks in very rapidly, effectively, in terms of selecting the minimum number of correct actions required, safely, in terms of reducing the number of incorrect actions, and productively, in terms of completing the task successfully in less time. In addition, the doctor's cognitive load was reduced by decreasing the number of actions required per view.

More case studies will be evaluated in our future work to determine the applicability of the HCI principles on MUI in different domains and to different types of healthcare application. Moreover, the approach will be compared to the MUI design of the same application without applying the corresponding HCI principles.

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