Estimating Cognitive Overload in Mobile Applications for Decision Support within the Medical Domain

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Keywords: Mobile, Interface Design, Complexity, Human Factors, Ehealth.

Abstract: Mobile applications have the potential to improve the quality of care received by patients from their primary care physicians (PCP). They can allow doctors to access the information they need when and where they need it in order to make informed decisions regarding patients' health. They can also allow patients to better control conditions such as Diabetes and Gaucher's disease. However, there are a number of limitations to these devices, such as small screen sizes and limited processing power, which can produce cognitive overload which in turn can negatively impact upon the decision making processes. This paper introduces a new research direction which aims to predict, during the development of mobile health care applications, when cognitive overload is likely to occur. By identifying the user's previous level of experience, their working memory, the complexity of the interface and the level of distraction imposed by the user's context, a prediction can be made as to when cognitive overload is likely to occur.

1 INTRODUCTION

Decision making is a critical component in effective healthcare. However in order for decisions to be made effectively within this domain, a large volume of information is required. Physicians typically have less than 5 minutes to make life and death decisions meaning that for them to be effective they require information to be presented in an efficient manner, sometimes within remote locations.

The proliferation of mobile devices has allowed for software applications to be accessed in a variety of contexts. Within the medical domain, physicians can use these devices to access patient records, prescribe medication and monitor patients in hospital no matter where the physician is. In a survey carried out by the PriceWaterhouseCoppers' Health Research Institute (HRI) (PriceWaterhouseCooper, 2010) it was found that two thirds of physicians said they were using personal devices for mobile health solutions which are not connected to their practice or hospital IT system. Indicatively, 56% of physicians stated that mobile devices expedite their decision making, while 39% claimed that the time needed for administrative tasks is decreased significantly.

Mobile devices impose a number of limitations, such as small screen size and limited connectivity, which negatively affect the usability of mobile applications (Zhang and Adipat, 2005). These limitations, as well as complex design practices due to a lack of design guidelines for mobile application development will further impede decision making within the medical domain as further cognitive load will be placed on the user.

To minimise the impact of the user interface on decision making within the medical domain, this position paper proposes a method for predicting when cognitive overload will occur. Using this approach, application designers can determine, during mobile application development, if cognitive overload will occur and can redesign the interface if necessary. The current method proposes the use of four factors to estimate cognitive load: user expertise, working memory, interface complexity and level of environmental distractions.

Flood D., Germanakos P., Harrison R., Mc Caffery F. and Samaras G..
Estimating Cognitive Overload in Mobile Applications for Decision Support within the Medical Domain.
DOI: 10.5220/0003971501030107
In *Proceedings of the 14th International Conference on Enterprise Information Systems* (ICEIS-2012), pages 103-107
ISBN: 978-989-8565-12-9

2 AIMS

The aim of this research is to design a cost effective way for developers to determine if cognitive overload will occur while using their mobile application. To accomplish this, it is proposed to determine the cognitive load of an application based on a number of factors; the users' level of expertise in the area, their working memory, the complexity of the interface and the level of distraction imposed by the context in which the application will be used. The following sections outline each of these factors in more detail.

2.1 User's Expertise

The first factor considered is the user's level of expertise within the task domain. It is believed that if a user is experienced within the task domain then he/she will be able to process more information thus prolonging the point at which cognitive overload will occur. In contrast to this, users without any domain expertise will require additional cognitive processing to understand the meaning of the information displayed by the application, thereby inducing cognitive overload sooner. For the purposes of this work the user's level of expertise will be divided into three categories; *Novice*, *Intermediate* and *Expert*. The classification of the expected end user will be determined by the application developer. However, there are a number of factors that can help to determine the level of expertise users have, for example, level of knowledge of the task domain and experience within the task domain.

2.2 Working Memory

Incorporating human factors in the interaction process is always a challenge. For the scope of this work, Working Memory (WM) has been employed, since it is considered a vital mechanism of the cognitive processing efficiency and has a direct influence on the design of user interfaces. According to Baddeley (1992), "the term working memory refers to a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning". Each individual has a specific and restricted memory span. The aim is to decrease the possibility of cognitive load in a mobile hypermedia environment by altering the amount of simultaneously presented information. This can be achieved with the manipulation of the link or content structure of a mobile application to achieve maximization of comprehension capabilities while users are performing a cognitive task.

2.3 Interface Complexity

One of the biggest challenges to the work presented here is defining interface complexity. It is believed that as the complexity of the interface increases so too does the cognitive load on the user. The complexity of the interface could be considered as the sum of the complexity of the individual components used. One approach to measuring the complexity, is to assign each component type a complexity rating, where simple components, such as a label or radio button, are given a lower complexity than more advanced components, such as a graph or chart. Using these ratings the interface complexity can then be rated as the sum of all components on the interface. It is proposed to determine the complexity rating that should be assigned to each component through a series of controlled experiments.

2.4 Distractions

When considering mobile applications, the context in which the application is used is continually changing. Zhang and Adipat (2005) suggested that context is more than just the location of the user. It also includes their interaction with nearby objects, and environmental elements that may distract the user's attention. Distractions of the user's attention can inhibit their ability to process information and therefore introduce extra cognitive load. The level of distraction experienced by the user will be divided into three categories; *Low* (a quiet area where a user can concentrate completely on the task), *Medium* (an environment in which the user may not be distracted but will be subjected to some background noise) and *High* (a noisy environment where the user will be distracted by either additional tasks or by other individuals).

2.5 Predicting Cognitive Overload

Using the factors identified above, it is believed that a reliable estimation can be made as to when cognitive overload is likely to occur. Through experimentation, outlined below, this work aims to investigate under each combination of the factors previously identified when cognitive overload will occur. A decision table will then be produced as a reference guide for mobile medical decision support application developers. When deciding between different interface designs, the developers can refer to this decision table to determine if each design will produce cognitive overload which would reduce the users' experience of the application. This approach will allow developers to determine earlier in the development cycle, and in a less costly manner, if the proposed design will provide a usable experience for the end-user.

3 HYPOTHESES

In order to validate the above approach a number of hypotheses are proposed. The first step will be to determine if each of the factors outlined above do impact cognitive load. Hypotheses 1 to 4 have been formulated to investigate this. *H1: A user's expertise is inversely proportional to cognitive load; H2: Working memory is correlated to cognitive load; H3: Cognitive load is proportional to interface complexity; H4: Cognitive load is proportional to the level of distraction to the user's attention*. The next step of this research is to then determine the impact of cognitive overload on effective decision making. This is captured through hypothesis 5 – *H5: High cognitive load hinders decision making*. Once these hypotheses have been explored the next step is to determine the combination of the identified factors with which cognitive overload will occur. The following research question will be used to guide this work – *RQ1: When does cognitive overload occur in terms of User expertise, working memory, interface complexity and level of distraction?* To test the hypotheses and answer the research question, a series of controlled experiments will be conducted.

4 FUTURE WORK

In order to determine when cognitive overload will occur, the cognitive load on a user first needs to be established. The level of cognitive load on a user is reflected in the time it takes a user to complete a given task effectively. A longer time to complete a given task indicates a higher cognitive load. In addition to this the effectiveness of the user at completing the task will also be considered. In each of the experiments presented below the effectiveness and efficiency of the user to complete the task will be taken as an indirect measure of cognitive load (Oviatt, 2006). The point at which cognitive overload occurs will be determined through a structured questionnaire that will be provided to participants at the end of each trial.

4.1 Hypothesis 1: A User's Expertise is Inversely Proportional to Cognitive Load

For the first experiment twenty participants will be recruited and divided into two groups, Novice and Expert, based on their expertise with interpreting blood pressure readings. The participants will be shown five readings and asked in each case to state whether the patient has high, low or normal blood pressure. For each reading the effectiveness (accuracy of their decisions) and efficiency (time taken for participants to make a decision) will be recorded. When the participant has completed all 5 trials they will then be given a questionnaire to evaluate the perceived level of cognitive load they experienced during the trial – *Dependent Variables:* Effectiveness, efficiency, and perceived cognitive load. *Independent Variables:* User Expertise.

4.2 Hypothesis 2: Working Memory is Correlated to Cognitive Load

All participants will go through a series of WM span tests (identifying the visual memory and central executive/verbal storage) using a Web-based environment. At first, the WMTB-C (Pickering & Gathercole, 2001) will be used for measuring both the central executive function and the verbal storage ability (phonological loop span), providing an indication of users' WM ability. Secondly, a WM test to measure the visuo-spatial sketchpad will be used. In total, users are classified as "low", "normal", or "high" accordingly, with respect to their ability, based on a calculated aggregated score of all tests. Once WM span has been identified, users will interact with a number of mobile environments varying in complexity. Navigation time as well as accuracy on reaching their expected cognitive target will be measured and calculated along with the value of their WM levels. – *Dependent Variables:* Effectiveness, Decision time. *Independent Variables:* Working Memory Span.

4.3 Hypothesis 3: Cognitive Load is Proportional to Interface Complexity

During this experiment the participants will be subjected to two alternative interfaces, one with high interface complexity (a graphical representation) and one with low interface complexity (a textual representation), displaying a patient's blood pressure. The participants will then be asked to evaluate whether each of the patients has high, low or average blood pressure. As with previous experiments, effectiveness and efficiency will be used to determine the level of cognitive load on the user. To counter any learning effects that may occur between trials, participants will be presented the interfaces in a random order – *Dependent Variables:* Effectiveness, Decision time, and perceived cognitive load. *Independent Variables:* interface complexity.

4.4 Hypothesis 4: Cognitive Load is Proportional to the Level of Distraction to the User's Attention

In this experiment each participant will be again asked to judge whether a patient has high, low or average blood pressure in each of five cases. In this experiment however, the participants will be placed in two environments; a quiet office with no distractions and an environment with a high level of distraction. As with previous experiments, effectiveness and efficiency will be used in conjunction with a subjective questionnaire to determine the level of cognitive load on the user. To counter any learning effects that may occur between trials, the participants will be presented the interfaces in a random order – *Dependent Variables:* Effectiveness, Decision time, and perceived cognitive load. *Independent Variables:* level of distraction.

4.5 Hypothesis 5: Cognitive Load is Correlated to Effective Decision Making

Using the data in each of the previous experiments the participants' effectiveness will be evaluated in terms of the perceived cognitive load. It is believed that participants' effectiveness and efficiency will be reduced as the cognitive load is increased. Statistical methods, such as Pearson's correlation test, will then be used to determine the strength of the relationship between cognitive load and effectiveness and efficiency. For each participant in each study, the number of correct determinations made in addition to the time taken will be rated against the level of cognitive load experienced by the participant.

RQ1: When will cognitive overload occur in terms of User expertise, working memory, interface complexity and level of distraction?

To answer this research question, a series of experiments will be conducted which will examine each combination of the previously identified factors. In each experiment one instance of each factor will be combined and the cognitive overload will be examined. Upon completion of these studies it will be possible to create a decision table, similar to the one presented below, estimating when cognitive overload will occur.

Table 1: Example cognitive overload decision table.

User Expertise	Working Memory	Interface complexity	Level of Distraction	Cognitive Overload
Expert	High	Low	Low	No
Expert	Low	High	High	Yes

5 CONCLUSIONS

Decision making is a critical component of health care. Ineffective decision making can have serious consequences, sometimes resulting in fatalities. An important component of effective decision making is the ability to access relevant information in an efficient manner. Through the use of mobile technologies, PCP can access information almost anywhere when they need it. Mobile applications, however, suffer from a number of usability issues which negatively impact a user's cognitive load, which will reduce the effectiveness of decisions that are made with the support of these devices.

This work proposes the development of a decision table that will support mobile application developers in predicting if cognitive overload will occur with a particular application.

ACKNOWLEDGEMENTS

This research is supported by the Science Foundation Ireland (SFI) Stokes Lectureship Programme, grant number 07/SK/I1299, the SFI Principal Investigator Programme, grant number 08/IN.1/I2030 (the funding of this project was awarded by Science Foundation Ireland under a co-funding initiative by the Irish Government and European Regional Development Fund), and supported in part by Lero - the Irish Software Engineering Research Centre (http://www.lero.ie) grant 03/CE2/I303_1, the EU project CONET

(INFSO-ICT-224053) and by the project smarTag (Internal funded projects of the University of Cyprus).

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