



Sizing Prenatal mPHRs using COSMIC Measurement Method

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Abstract

This paper presents an empirical evaluation of the COSMIC Function Points method (e.g., ISO 19761) through measuring the functional size of 33 prenatal mobile Personal Health Records (mPHRs) apps. This evaluation compares the functional size of each mobile app measured using the COSMIC method to the score of the app obtained in a previous evaluation that relied on functions extraction using a quality assessment questionnaire. It includes as well an investigation of the relationships between the functional sizes of these apps, their ratings in the apps stores, as well as the number of installs. As results, it was noticed that there is a considerable shift between the rankings of the functional sizes and the functionality scores obtained in the opinion-based questionnaire, for most of the apps assessed. Moreover, the study of the relationship between the functional sizes and the ratings, as well as the number of installs indicated that these variables are not linked, since they are impacted by external factors. The findings support the use of the COSMIC method for these apps in regard to measuring the functional size for further updates or improvements, which can also help developers to have an overview about the existing apps on the market and compare between them. Moreover, COSMIC is more effective since it covers all the features and functionalities of prenatal mPHRs.

Keywords COSMIC · Prenatal · Pregnancy monitoring · Mobile personal health records · mhealth · Functional size measurement · ISO 19761

Introduction

Mobile applications (e.g., apps) are software applications designed to run on smartphones, tablets or other mobile devices [1, 2]. According to statistics performed by August 2019, the number of apps available for download in leading app stores is: 2.46 million apps in Google Play Store and 1.96 million apps in Apple's App Store [3]. Moreover, the development of mobile apps is considered relatively easier than web or

desktop apps. In addition, their availability and lower price encourage usage: thus, this industry experiences considerable growth in apps development each year.

Mobile health (mhealth) apps are applications that refer to medicine and health services through mobile devices. The health, fitness and medical industries have been identified as the top three fields to accelerate the growth of mobile devices [4]. For instance, more than 84,000 mobile apps were released for the medical and health & fitness markets in 2017 [5].

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Mobile Personal Health Records (mPHRs) apps for prenatal (or pregnancy monitoring) are mhealth apps dedicated for pregnant women in order to track pregnancy [6]. In a previous work [7], a review of the mPHRs for pregnancy monitoring was conducted by applying the Systematic Literature Review (SLR) protocol in the analysis process. The method followed to perform this analysis included developing a quality assessment questionnaire, based on a rigorous review of the scientific literature on pregnancy and mobile applications available on the market. The quality assessment questionnaire was then applied to a set of mPHRs apps for pregnancy monitoring (available on iOS and Android apps stores), in order to analyze these apps features and functionalities that were specific to pregnancy monitoring.

In contrast to this classical and qualitative method for assessing the functionality of pregnancy monitoring mPHRs, Functional Size Measurement (FSM) methods offer an objective quantification of the functional size of such apps. FSM methods measure the software size in terms of functions required by the users, rather than how software is implemented. For example, it provides software size as an input to a number of the software effort estimation techniques and tools [8].

The COSMIC Function Points, is the second generation of FSM methods and it was designed by the Common Software Measurement International Consortium (e.g., the COSMIC Group) based on fundamental principles of software engineering and metrology. COSMIC is applicable to business, real-time and infrastructure software, complying with the standard ISO/IEC14143/1 [8]. The COSMIC method has several assets, such as being publicly available and applicable to a wide range of software and its underlying concepts are compatible with modern concepts of software engineering [9].

Efficient and standardized development processes for the pregnancy monitoring mPHRs require an evaluation of their size, which can be carried out by using a functional size measurement method. Therefore, we used in [10] the COSMIC method to measure the functional size of 17 free pregnancy monitoring mPHRs selected from [7] and are available in the Google Play and Apple App Stores. Thereafter, the COSMIC functional size values were compared with those obtained using a qualitative questionnaire [7]. The aim of this comparison was to empirically apply the COSMIC method on mPHRs for pregnancy monitoring, in order to identify its accuracy as regards measuring the functional size of these apps compared to a qualitative method that relies on objectivity using a quality assessment questionnaire.

To the best of our knowledge, our research work [10] was the first to apply and analyze the use of COSMIC method on mhealth apps, in particular on mPHRs for pregnancy monitoring. In the present study, we extend the study in [10] by:

1. Updating the set of mPHRs with a selection of 33 free prenatal mPHRs apps available in Apple App store and

Google Play store, which are updated after the 1st of January 2018. (Note [10] used only the 17 prenatal mPHRs apps updated after the 1st of January 2014 [7]).

2. Investigating two other research questions to study the relationships between the COSMIC functional size values, of the selected prenatal mPHRs, and the ratings of users in the apps stores, in addition to their number of installs.

Therefore, the present study compares the COSMIC functional sizes of the 33 selected prenatal mPHRs with:

- (1) Functionality scores obtained by using the questionnaire-based evaluation in [7],
- (2) Users' ratings in app stores, and
- (3) Numbers of installs.

Hence, three research questions are answered and discussed:

- **RQ1:** Does the standard-based COSMIC functional size provide a functional ranking of prenatal mPHRs similar to the functional ranking using the opinion-based questionnaire in [7]?
- **RQ2:** Is there a relationship between the COSMIC functional size of prenatal mPHRs and their users' ratings in the app stores?
- **RQ3:** Does a high COSMIC functional size imply a higher number of installs of the 33 selected prenatal mPHRs?

The remainder of this paper is structured as follows: Section 2 introduces the concepts and methods used in the present study, in particular mPHRs applications and the COSMIC Function Points method. Section 3 introduces the related work on the application of COSMIC method on mobile applications. A description of the method used in this study is presented in Section 4. Section 5 presents and discusses the findings of this study. Finally, the conclusions and future works are presented in Section 6.

Background

This section provides an overview of the mPHRs for pregnancy monitoring, along with a brief description of the COSMIC Function Points method.

MPHRs for pregnancy monitoring

PHRs are private apps that allow patients to add and access their own medical and health information [11], which may promote the doctor-patient communication and reduce the risk

of medical errors [4]. A PHR should include all pertinent health information such as family history, immunizations, medications, laboratory tests, and genetic information [12]. A PHR can be either: USB-Based, desktop application, web-based application or mobile application (mPHR) [12].

An mPHR is a mobile application that allows users to access, coordinate their health data through their mobile devices and to make relevant data available to those who need it [13]. MPHRs have been considered as a point of interest for several research studies. MPHRs are available for chronic diseases such as cardiovascular diseases [2], diabetes [14] or obesity [15]. They are also used for specific health conditions such as pregnancy, which requires specific monitoring during the 40 weeks. MPHRs for pregnancy monitoring provide several functionalities to help the pregnant woman keep track of her health status and the health of her baby, including tracking the weight and blood pressure, providing guides for nutrition and physical exercises during this period, recording the baby movements and contractions and following the progress of pregnancy during all its stages [7].

Functional size measurement: COSMIC

According to the standard ISO/IEC 14143/1:2011 [8], a functional size is defined as “a size of software derived by quantifying the functional user requirements”. Functional size measurement (FSM) is used to measure the productivity in the software development and to estimate the effort and duration of software projects [8]. Five FSM methods have been adopted as ISO standards [9]: (i) ISO 19761-COSMIC; (ii) ISO 20926-IFPUG; (iii) ISO 20968-MKII, (iv) ISO 24570-NESMA; and (v) ISO 29881-FISMA.

The FSM method used in this study is ISO 19761-COSMIC Function Points. The COSMIC method is designed to measure the functionality of: business application software, real-time software, infrastructure software and some types of scientific and engineering software [16]. The COSMIC method has two models based on fundamental software engineering principles: the ‘Software Context Model’, which enables to define the software to be measured and the size measurement, and the ‘Generic Software Model’, which defines how the Functional User Requirements (FURs) of the software to be measured are modeled so that they can be measured [16]. The COSMIC method consists of 3 phases: (1) The Measurement Strategy Phase: it is the preliminary phase in which the key parameters of the measurement are defined carefully [16]. (2) The Mapping Phase. In this phase, the functional processes are identified from the available FURs, in addition to the object of interest, the data groups and the data movements, as described in [16]. (3) The Measurement Phase: The data movements are counted in this phase, by associating 1 COSMIC Function Point (CFP), which is the measurement unit, to each data movement of a data group. Thus, they are

summed up to represent the functional value of the measurement. The measurement process is more detailed in [16].

The present study applies the most recent version of the COSMIC Measurement manual: Version 4.0.2 [16].

Related work

This section introduces the related work on the analysis of functionalities for Personal Health Records (PHRs), and on the use of the COSMIC method to measure the functional size of mobile apps.

PHRs: Analysis of functionalities

Previous studies have been conducted in order to analyze the features and functionalities of PHRs.

In [17], the functionalities of Web-based PHRs were analyzed and assessed according to health information, user actions and connection with other tools: this SLR selected 19 free Web-based PHRs from the 47 PHRs identified. The findings showed that none of the PHRs selected met all of the functions analyzed in the study. In [13], the content, functions, security and marketing characteristics of mPHRs were previously evaluated for iOS, Blackberry and Android. Nineteen mPHRs were selected and evaluated. The evaluation of the mPHRs covered the product characteristics, data elements, application features and marketing tactics. The study found that none of the mPHRs included all the evaluated aspects.

In our previous study [7], we analyzed the features and functionalities of 33 pregnancy monitoring mPHRs for iOS and Android, which were selected from Apple App store and Google Play store, respectively. The evaluation was conducted according to nine data items (e.g., calendars, pregnancy information, health habits, counters, diaries, mobile features, security, backup, configuration and architectural design) and 35 questions included in a quality assessment questionnaire. We found that none of the mPHRs selected met 100% of the functionalities analyzed. Moreover, the highest score achieved was 77%, while the lowest was 17% [7]. The findings of this study concluded that mPHRs for pregnancy monitoring should cover largest areas of pregnancy for an accurate and complete tracking, in addition to the use of the mobile features in order to provide a wide use of these mPHRs. Moreover, it was noticed that the security of mPHRs for pregnancy monitoring needed to be improved.

COSMIC functional size measurement for mobile applications

Measuring the functional size of mobile applications is fairly recent [18–23].

The empirical study in [18] used the COSMIC functional size of eight Android mobile applications to estimate the amount of needed memory and get accurate code size predictions, in addition to identify some possible recurrent patterns for the measurement. This study reported that it is possible to accurately predict the needed memory for mobile applications.

The case study in [19] of the mobile game application Angry Bird aimed to demonstrate how UML (Unified Modeling Language) representations improve the use of COSMIC measurement by mapping the UML context with COSMIC FSM rules and measurement. The approach used in this study is based on use case diagram, behavioral model elements, component diagram, object diagram and sequence diagrams where the UML designs are assigned from the basic functional requirements and workflow requirement of Angry Birds mobile application. In addition, the case study showed that building UML models according to the COSMIC measurement rules, eases measurement procedures and can be used as a guideline for functional size measurement.

A COSMIC-based approximation method was introduced to quickly and accurately measure the functional size of mobile apps in [20].

The COSMIC method was applied on a mobile application that provides a basic course management. The study concluded that COSMIC is suitable to measure the functional size of a mobile app [21]. However, some characteristics of the mobile application development, such as non-functional requirements and small teams and projects might represent serious limitations for these apps. The study also proposed an approach relying on the screen types with different complexity and their corresponding CFPs, which may decrease the estimation effort.

A Use Case-based measurement method was proposed in [22] to estimate the functional size of mobile and web applications using the COSMIC method: it is based on a set of measurement formulae evaluated through the COSMIC case study of a restaurant management system. These formulae were compared to other approaches in order to validate them. Moreover, an experimentation was conducted by three UML experienced practitioners, by applying the proposed measurement formulae to measure the functional size of three mobile functional processes and three web functional processes. The experimentation showed that the measurement formulae can provide the same correct measurement, a close value or a different value.

Furthermore, in a review of the measurement process and rules used by FSM for mobile applications and UML modelling [23], it was found that most of the literature adopted FSM in the estimation of the app development effort. However, some literature used FSM with UML modelling, since UML model can represent the functional requirement of a mobile application.

Method

MPHRs for pregnancy monitoring belong to business applications, which are characterized by managing large amount of data about events and objects in the real world related to business administrations [24]. Therefore, COSMIC can be applied to measure the functional size of these apps.

This study targets mPHRs for pregnancy monitoring running under Android and iOS platforms, the leading mobile operating systems and the preferred for mhealth apps development [25].

These apps were the result of a selection process initially conducted in [7], which has been revised and updated in May 2019. The revised selection of the mPHRs for pregnancy monitoring [7] targeted Apple App store and Google Play store as the sources for the selection of these apps. The terms, keywords and the four inclusion criteria used in [7, 10] were kept for the updated selection, while a single exclusion criterion (EC1) was used:

- Inclusion criteria:
 - **IC1:** Free apps for iOS and Android available in Apple App store and Google Play store, respectively.
 - **IC2:** Apps that are in the Health & Fitness or Medical category in Apple App store or Google Play store.
 - **IC3:** Apps that were updated after the 1st of January 2018.
 - **IC4:** Apps that focus on pregnancy monitoring.
- Exclusion criterion:
 - **EC1:** The app is not in English.

Upon applying the first inclusion criterion IC1, 496 applications were selected. After applying IC2, the number of apps selected was reduced to 295. Next, 66 outdated apps were eliminated based on criterion IC3 and 174 apps were discarded next by applying IC4 for not focusing on pregnancy monitoring. Two other apps in Russian and Hindi were also excluded based on EC1. Moreover, after applying these inclusion and exclusion criteria, 20 apps were excluded because they were not working or their access was restricted. Note that if an mPHR was selected for both iOS and Android, they were counted as a single mPHR after checking their similarity. Hence the total of the selected apps for this study is 33. The complete selection process is described in Fig. 1.

The method used in the present study is thereafter described and consists of the three phases of COSMIC:

a. Measurement Strategy Phase

The main parameters of this phase are identified as follows:

- The purpose: The COSMIC size of FURs of the selected mPHRs for pregnancy monitoring is to be compared with their functional scores obtained in [7] based on a regular

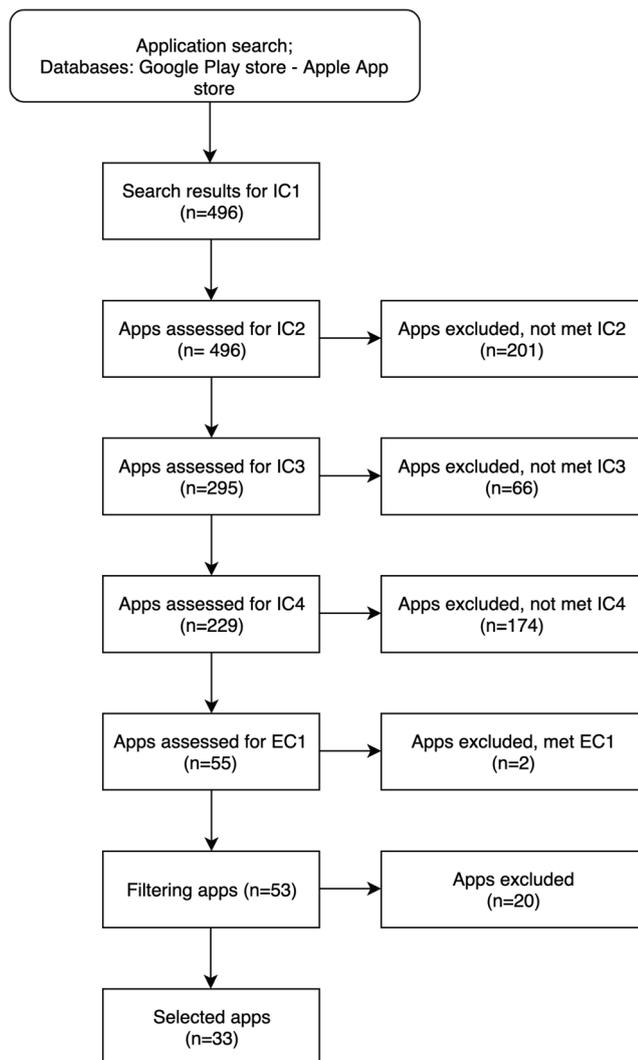


Fig. 1 Selection process of the mPHRs for pregnancy monitoring

method relying on functions extraction. These scores represent the number of features and functionalities analyzed that are present in these apps, according to the data items used. The relationships between these functional sizes and the ratings and number of installs, for the selected mPHRs, are also to be studied.

- The overall scope: The measurement of all the FURs within the selected apps only. The FURs executed in external apps are excluded from this measurement. Therefore, only the data movements between the external apps and the measured apps are considered within the sizing and comparison scope.
- Functional users: the functional users in this case are human users, which are pregnant women, that use the mPHRs for pregnancy monitoring.
- Layer: a mobile app is considered as an application layer, which is developed on the top of other layers [20].
- Level of granularity: the measures are at the level of the screens of each mPHR for pregnancy monitoring.

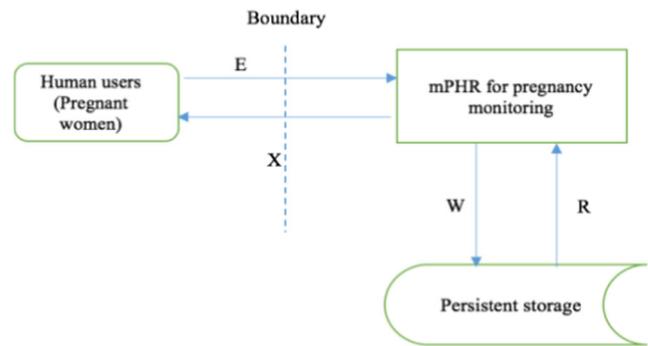


Fig. 2 Context diagram. Acronyms: Entry(E), Exit (X), Write (W) and Read (R)

To visualize the interactions between the defined key parameters at this stage, Fig. 2 demonstrates the context diagram of the measurements conducted in this study: it presents the measured software, along with its functional users, the boundary, the persistent storage and the movements of data between them [16].

b. Mapping phase

A functional user starts a functional process in response to a triggering event. In the case of mPHRs for pregnancy monitoring, the triggering events are the users’ inputs. Moreover, FURs can be mapped into unique functional processes, which are identified in this phase, for each selected mPHR for pregnancy monitoring, along with the objects of interest, data groups and data movements. The functional processes can be extracted based on each screen of the mobile apps [21]. In this study the authors installed each mPHR for pregnancy monitoring, then browsed the features and functionalities listed in each screen in order to extract the functional processes: this leads to the identification of the types of data movements (Entry (E), Exit (X), Read (R) or Write (W)) within these apps.

In this study, the mPHRs for pregnancy monitoring were considered as being used for the first time for the extraction of the functional processes, which allows the progression of the processes be followed while using the apps, and to extract some processes that are generally executed only while using the app for the first time, such as creating a profile or setting the due date.

c. Measurement phase

In this phase, the data movements were counted based on the measurements that have been conducted according to some common cases [18] such as create, select, delete, add, share and display, which can be repeatedly executed by the user, which has facilitated the measurement process. The measurements were conducted independently by the first two authors. Any measurement discrepancies were resolved through discussions.

Results and discussion

This section presents and discusses the results of RQs 1–3. First, we compared the functional ranks of the 33 prenatal mPHRS according to COSMIC and the methodology in [7]. Second, We evaluated the relationship between COSMIC functional sizes of the prenatal mPHRS and their users’ ratings. Third, we assessed the relationship between the COSMIC functional sizes of the selected prenatal mPHRS and their number of installs.

RQ1: Does the standard-based COSMIC functional size provide a functional ranking of prenatal mPHRS similar to the functional ranking using the opinion-based questionnaire in [7]?

This research question aims to compare standard-based COSMIC functional size values of the selected mPHRS with their functionality scores obtained in our previous work [7].

Of the 33 mPHRS selected for this study, 17 had been already assessed in [10] using both the COSMIC and the methodology of [7]. We therefore evaluated in this study the functional sizes of the 16 remaining mPHRS.

Next, a ranking of the 33 apps was established based on both evaluations: COSMIC functional size and the functionality scores of [7].

Figure 3 presents the functionality scores of the 33 apps using the quality assessment of [7], ordered in descending scoring. It is noticed that, the app *Pregnancy & Baby App – Nurture* achieved the highest score of provided functionalities (27), while the app *iBirth™ Daily*

Pregnancy, Postpartum & Baby Tracker achieved the lowest score (9).

Next, Fig. 4 presents the COSMIC functional size values of the 33 apps, ordered in descending functional size. It is noticed that, the app *Woman’s Pregnancy* obtained the highest COSMIC functional size of 585 CFP, while the app *Pregnancy mode free* obtained the lowest functional size of 33 CFP.

The differences noticed between the functional sizes may be due to the number of functions for each purpose provided by the apps, where the apps may have multiple purposes and each purpose may provide a different number of functionalities.

Furthermore, while the overall differences between the functionality scores based on a qualitative evaluation are relatively small, there is a considerable larger variability in the COSMIC functional sizes of the measured apps.

Regarding congruence in terms of comparative ranking between functionality scores and the COSMIC functional size, as shown in Fig. 5:

- A) 26 apps got a significant ranking variation (i.e. higher or equal than three shifts), such as for *Pregnancy tracker and Baby Due Date Calculator* (Score ranking:7, Functional size ranking:25), *Woman’s Pregnancy* (Score ranking: 12, Functional size ranking: 1), *I’m pregnant / Pregnancy App* (Score ranking: 25, Functional size ranking:7), *Baby Box Pregnancy calendar, organizer, tracker & contraction timer* (Score ranking: 18, Functional size ranking: 31).

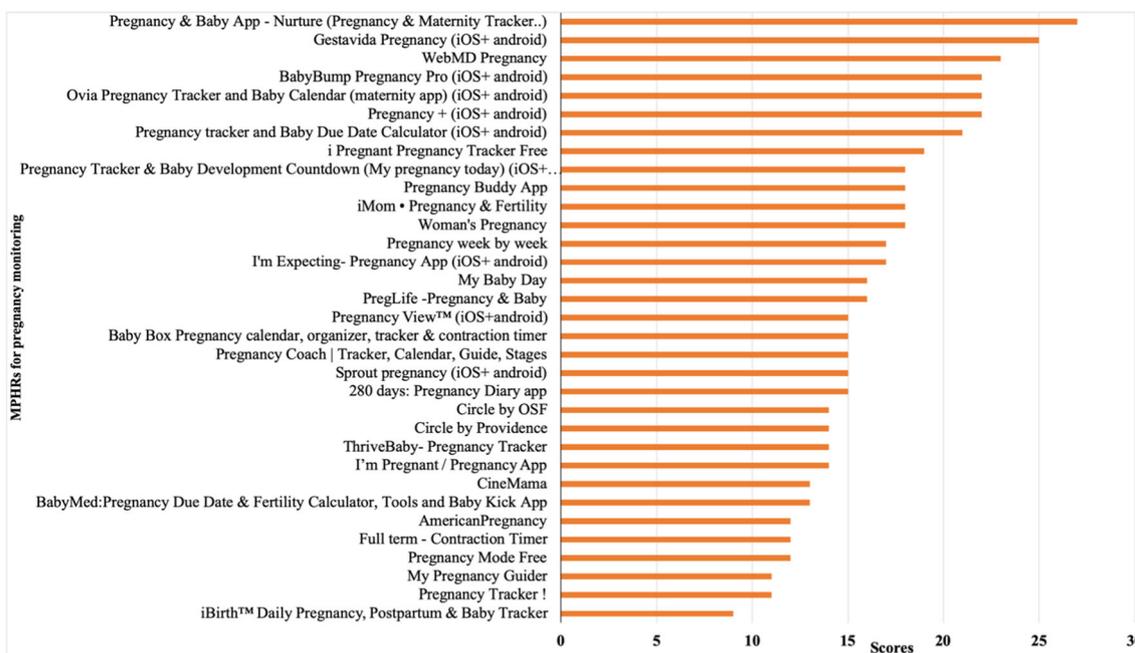


Fig. 3 Functionality scores of the 33 mPHRS using the qualitative assessment of [7]

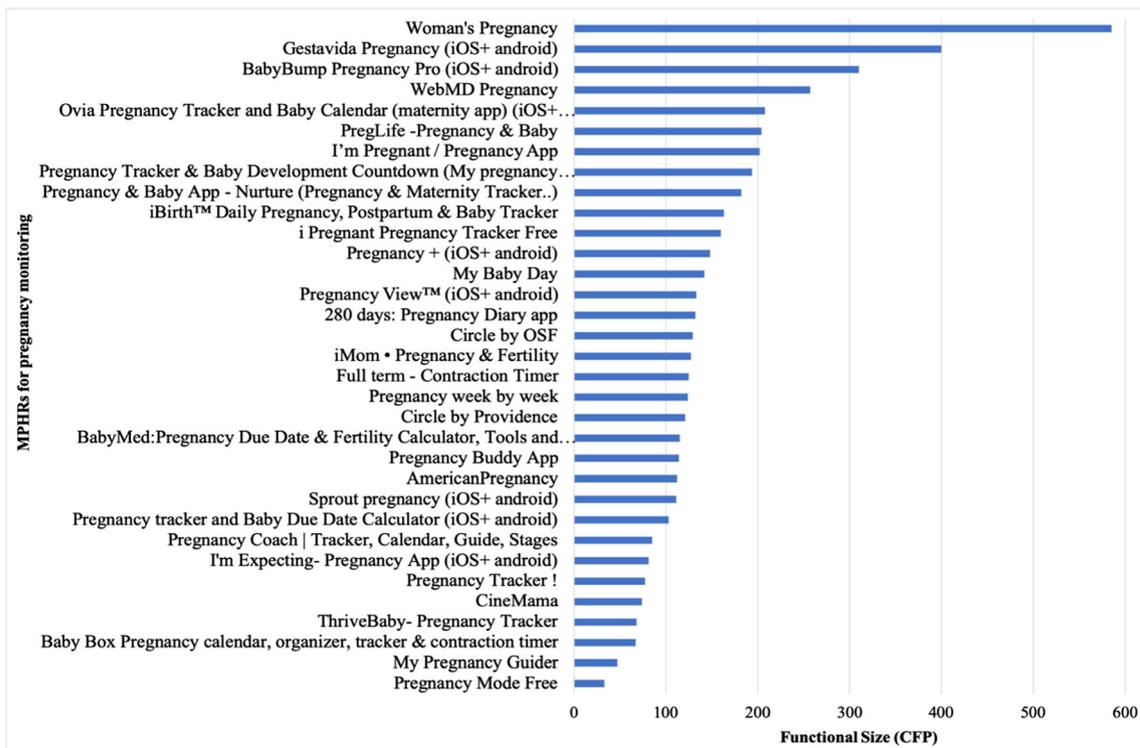


Fig. 4 COSMIC Functional sizes of the 33 mPHRs for pregnancy monitoring

B) 7 apps got only one or two ranks variation, such as: *WebMD Pregnancy, BabyBump Pregnancy Pro, My Pregnancy Guider, Pregnancy Tracker & Baby*

Development Countdown. This difference indicates that each criterion used (scores and CFP) ranked these apps quite similarly.

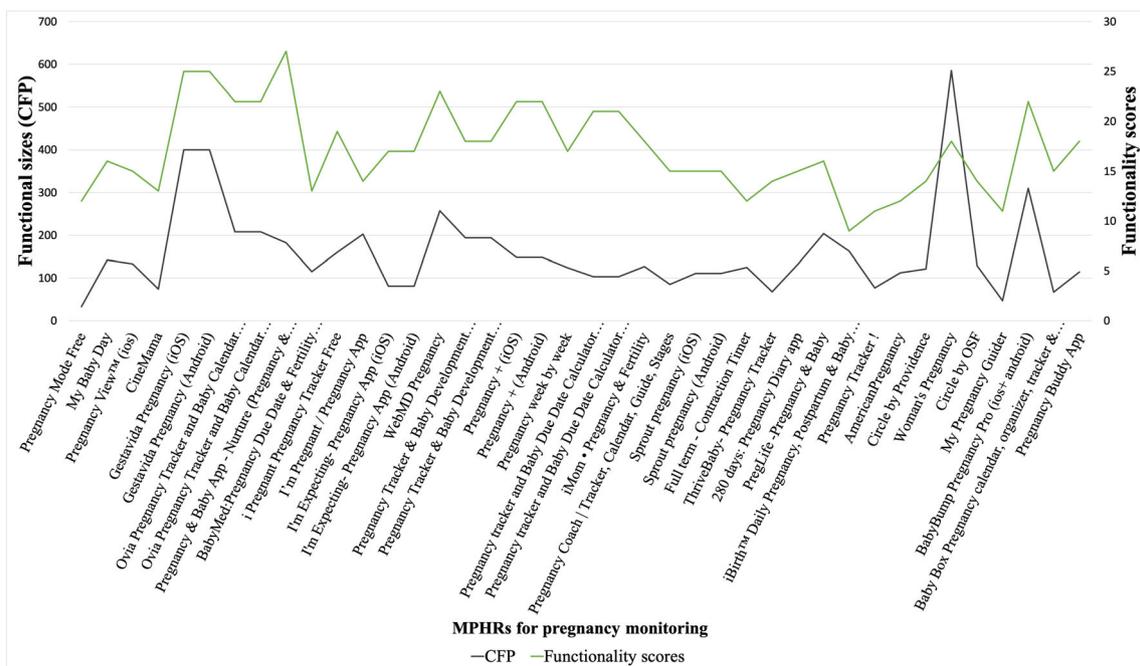


Fig. 5 COSMIC functional sizes and functionality scores of the 33 mPHRs for pregnancy monitoring

- C) Only prenatal mPHRs that got the same ranking in both cases are *Gestavida Pregnancy* and *Ovia Pregnancy Tracker and Baby Calendar (maternity app)*.

From these results, we can conclude that there was no important shift between the rankings of the COSMIC functional sizes and the rankings of scores for only 7 prenatal mPHRs out of 33.

The functional size was measured according to the COSMIC rules and guidelines and it covered the features and functionalities within the 33 apps. However, the scores obtained in the evaluation of features and functionalities have been calculated according to a quality assessment questionnaire that has been focusing only on pregnancy-oriented aspects. Hence, the difference noticed by using these two evaluations could be due to the fact that the scores are mainly related to pregnancy monitoring. Thus, they did not cover some complementary features and functionalities provided by these mPHRs. However, while measuring the functional sizes of the selected mPHRs for pregnancy monitoring, each and every data movement that can occur while using the apps was considered in the measurement.

It is deduced, hence, that the COSMIC method is flexible and suitable for the measurement of the functional size of mobile apps [21]. Moreover, the COSMIC FSM method is more accurate and practical to measure the functional size of mPHRs for pregnancy monitoring: it is based on a rigorous basis of the software engineering principles, and it is independent of the technologies used and the development methods. COSMIC can target a specific set of functionalities as well, in order to measure their functional size, instead of measuring the functional size of the entire mobile app.

RQ2: Is there a relationship between the COSMIC functional size of prenatal mPHRs and their users' ratings in the app stores?

To answer this research question, the ratings given by users in Apple App store for iOS apps and Google Play store for Android apps were extracted in May 2019. Only three apps did not have ratings available: *My pregnancy Guider*, *BabyBump Pregnancy Pro* (iOS and Android) and *Baby Box Pregnancy calendar, organizer, tracker & contraction timer*. The ratings on a scale of 1 to 5 stars reflect the feedback of users having installed and used the apps.

Figure 6 presents the ratings and COSMIC functional sizes of the selected mPHRs for pregnancy monitoring. It is noticed that:

- A) The ratings and functional sizes are proportional for only few apps such as *Gestavida Pregnancy* (Functional size: 400, Ratings for iOS: 5, Ratings for Android: 4), *Woman's Pregnancy* (Functional

size: 585, Ratings: 4.8), *WebMD Pregnancy* (Functional size: 257, Ratings: 4.5), *Cinemama* (Functional size: 74, Ratings: 2.6).

- B) There is no noticeable relationship between the ratings and functional sizes for the remaining mPHRs. Moreover, the bivariate correlation coefficient has been calculated to study the correlation between the ratings and functional sizes. Thus, no statistically significant correlation was found ($r = 0.1597$), which reveals a very weak relationship between the two variables.

This can be due to:

- i) The ratings given by the users are not based on specific criteria, and they are more related to their personal preferences regarding the features and functionalities included in these apps, or related to non-functional requirements such as usability, reliability, security and performance efficiency, which are not covered by the COSMIC method, since it measures only the functional requirements.
- ii) The measured functional sizes cover the overall features and functionalities of the selected mPHRs for pregnancy monitoring.
- iii) The number of raters influences the final average rating, which varies from one app to another. For instance, the number of raters for Android apps is mostly higher than for iOS apps, since Android is the most used mobile platform worldwide [26].

RQ3: Does a high COSMIC functional size imply a higher number of installs of the 33 selected prenatal mPHRs?

The number of installs was only available for Android apps (11 out of 33 mPHRs) and was extracted from Google play store to answer RQ3.

As shown in Table 1, the mPHR *Gestavida Pregnancy*, which obtained the highest functional size among the Android mPHRs for pregnancy monitoring, and the mPHR *Pregnancy Mode Free*, which obtained the lowest functional size among all the Android apps, are both installed in more than 10,000 devices. However, the mPHR *Pregnancy +* is installed in more than 10,000,000 devices, and obtained 148 CFP as functional size. This demonstrates that the number of installs is not related to the functional size, but may be increased by virtue of other factors, such as:

- A) When an app gets positive reviews and high ratings from app stores users, it raises its number of installs since some users refer to these two criteria before installing a new app.

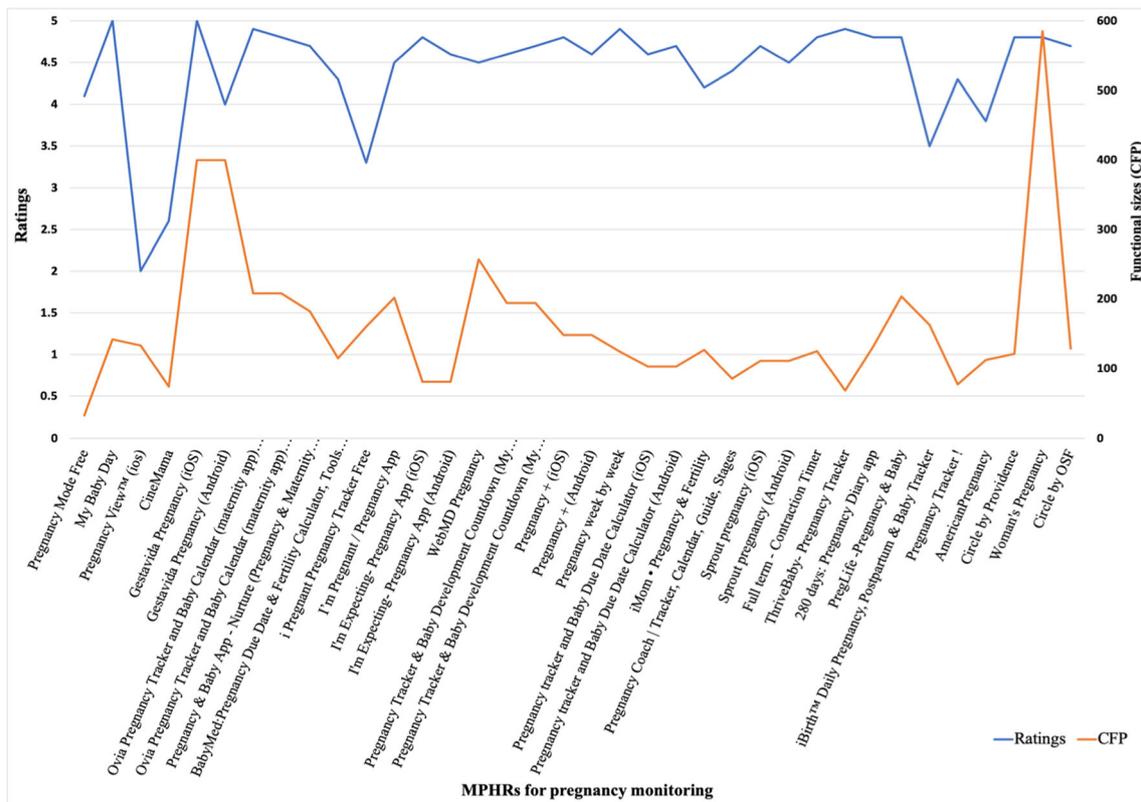


Fig. 6 COSMIC functional sizes and ratings of the 33 mPHRs for pregnancy monitoring

B) Significant efforts are made by mobile apps owners to promote their apps. It can be either by using various marketing strategies, such as paid advertising by investing in ad campaigns, or free methods like optimizing the store listing, or by using the right keywords in the app description and the title. Thus, their apps chances to earn a higher ranking in the search results are maximized and can reach more potential users.

Another factor also increases the number of installs, that is the app size: the limited storage of some devices, in addition to

the cost and network disconnection frequencies, especially in developing countries, lessens the installation of apps with a bigger size.

Conclusion and future work

For the empirical evaluation of the COSMIC method reported in the present study, the functional sizes of 33 mPHRs apps for pregnancy monitoring were measured and their size values in CFP units were compared with

Table 1 Functional size and number of installs of the 11 Android mPHRs for pregnancy monitoring

App name	Number of installs	COSMIC Size in CFP
Gestavida Pregnancy	10,000 +	400
Ovia Pregnancy Tracker: Baby Due Date Countdown	1,000,000 +	208
I'm Pregnant - Pregnancy Tracker	1,000,000 +	202
Pregnancy +	10,000,000 +	148
iMom • Pregnancy & Fertility	1,000,000 +	127
Pregnancy week by week	1,000,000 +	124
Sprout pregnancy	1,000,000 +	111
Pregnancy tracker and Baby Due Date Calculator	1,000,000 +	103
Pregnancy Coach Tracker, Calendar, Guide, Stages	5000 +	85
I'm Expecting - Pregnancy App	1,000,000 +	81
Pregnancy Mode Free	10,000 +	33

the functionality scores obtained in a previous study through an opinion-based questionnaire [7]. More specifically, three research questions were investigated. In summary:

A) For RQ1, we noted that: the shift between the rankings of both evaluations was small for only 7 of the selected apps, while it is considerable for the remaining apps.

COSMIC is a preferred method to measure the functional size of such apps, as it covers all features and functionalities, and gives an overview about the richness of the app contents according to the main purpose, which is tracking the health of the pregnant woman and her baby during pregnancy.

B) For RQ2 and RQ3, we studied the relationships between the COSMIC functional sizes of the selected mPHRs for pregnancy monitoring and their ratings and number of installs. Hence, it was concluded that these variables are not linked, since the ratings may be impacted by the personal preferences of the users or the number of raters, and the number of installs are impacted by the marketing strategies used to promote the app or the reviews given by users.

The findings of this study emphasize the use of the COSMIC method to measure the functional size of mobile applications. However, efforts need to be addressed as regards facilitating this measurement and applying it to mobile applications from other disciplines.

As for the developers of mPHRs for pregnancy monitoring, using COSMIC will provide valuable results that can be exploited to evaluate and compare the available apps on the market.

As future work, we intend to extend the application of the COSMIC method on other mhealth apps such as postnatal apps or blood donation apps, in addition to investigating the relationship between the functional size and the app size of prenatal mPHRs.

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Compliance with ethical standards

Conflict of interests All the authors declare that there is no conflict of interest regarding the publication of this paper.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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