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Original Research

ISO/IEC 25010-based Quality Evaluation of Three Mobile Applications for Reproductive Health Services in Morocco

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Abstract

Background: Mobile applications play a crucial role in postnatal, contraception, and prenatal care, offering vital monitoring and resources for mothers and infants. This study assessed the software product quality (SPQ) (the degree to which a software product meets specified requirements and user expectations) of three reproductive health monitoring mobile applications, employing ISO/IEC 25010 and ISO/IEC 25023 standards. The objective was to analyze the strengths and weaknesses of each app, thereby providing valuable information for potential users. By identifying areas requiring enhancement, this study improves the overall quality and usability of these applications. **Methods**: We implemented a three-step analysis process, examining the sub-features and features outlined in the ISO/IEC 25010 standard for software product quality, encompassing functionality, reliability, usability, efficiency, and maintainability. Subsequently, we formulated a checklist summarizing the influence of the three mobile applications on SPQ. Finally, we calculated the impact of each requirement block on both SPQ and quality in use (QIU) models. **Results**: The results show that the functional suitability SPQ characteristic is greatly influenced by the predefined requirements, with subsequent impacts on the operability, performance efficiency, reliability, and security SPQ characteristics. Thus, developers, designers, and testers must integrate these requirements across the developmental stages of health mobile applications to create a high-quality, patient-centered product with substantial added value. **Conclusions**: This study has produced a range of requirements tailored for pregnancy monitoring and childcare applications, serving as a valuable reference for developers aiming to create high-quality applications and evaluate their quality effectively. It underscores the importance of integrating SPQ characteristics into the software development process to ensure the creation of high-quality products with essential key performance indicators (KPIs). Such considerations facilitate better evaluations in application stores and increase user adoption and satisfaction levels.

Keywords: mobile applications; software product quality; reproductive health service; ISO/IEC 25010

1. Introduction

Effective monitoring and management of pregnancy are pivotal for ensuring a successful birth and the well-being of the mother and child. This responsibility can be shared among mothers, midwives, and healthcare professionals, who work collaboratively to maintain maternal health and prevent complications by providing essential reproductive health services. Access to high-quality reproductive health services is vital for maintaining overall well-being, particularly for individuals who cannot attend medical appointments due to their busy schedules or distance [1]. Furthermore, numerous studies have highlighted the role of technology and eHealth (electronic health refers to the use of digital technologies to support and improve healthcare services) applications in enhancing healthcare services' quality and facilitating data integration for monitoring and assessing patients' health status [2–4]. For example, electronic health records (EHRs) help improve clinical care, prevent complications, and enhance healthcare quality. Additionally, adopting EHRs can help bridge the quality gap in healthcare systems, especially in low- and middle-income countries (LMICs) [5]. The significance of eHealth has been further underscored by the coronavirus disease 2019 (COVID-19) pandemic, which has led to a rapid increase in the use of telemedicine via mHealth (mobile health: refers to the use of mobile devices to improve healthcare management) applications [6,7]. The successful implementation of these technologies during the crisis has demonstrated their effectiveness in managing public health emergencies [8–10].

Health monitoring applications tailored for pregnant women are pivotal in enhancing their well-being by improving communication with healthcare providers, streamlining the monitoring process, and facilitating convenient tracking of crucial information for prompt medical intervention during emergencies. Notably, research indicates that 73% of parents prefer receiving electronic discharge advice and leverage digital technology for research purposes, under-

scoring a clear inclination towards digital tools [11]. The rapid growth in smartphone application usage is evident, with a staggering 6.6 billion users reported in 2022, reflecting a 4.9% annual growth rate and a remarkable 79% increase from 2.9 billion users in 2016. This trend is anticipated to persist and even increase in the foreseeable future [12].

In 2021, the primary application stores offered a staggering array of over 400,000 health-related mobile applications, with a notable 25% dedicated to addressing health issues, particularly those concerning pregnancy. A systematic review conducted in Australia in 2017 identified 2052 pregnancy-related mobile applications accessible within the country, mirroring findings from various studies indicating women's reliance on digital resources like mobile applications for pregnancy monitoring and menstrual cycle tracking [13]. Moreover, recent research from Morocco underscores the increasing reliance on mobile health applications, emphasizing the necessity for accessible and reliable digital healthcare resources [14,15]. The proliferation of the Internet and the advancement of web and mobile technologies have significantly enhanced access to maternity information, making it more convenient and readily available [16]. Additionally, previous studies have shown that mHealth applications can positively influence healthy lifestyles and medical care, with lifestyle mHealth applications proving to be widely accepted, feasible, and capable of eliciting positive changes in health behaviors [17].

In our previous studies [18–20] and research as part of the PEER 7-246 project [21], we developed three Android applications aimed at improving access to reproductive health services for women in Morocco. The primary goal was to enable women to autonomously manage their reproductive health, regardless of their circumstances or conditions. Each application offers a specialized service, with detailed depictions of their interfaces in the Appendix Figs. 7,8,9.

- *Mamma&Baby* is a postnatal app primarily tailored to simplify the daily life of new mothers, offering a range of features to aid in organization and support during the postpartum period [20].
- *MaGrossesse* is a prenatal monitoring application aimed at helping pregnant women track their baby's growth and monitor changes in their bodies, fostering a deeper connection between mother and child [18].
- *MyContraception* provides a comprehensive solution for women seeking to prevent unwanted pregnancies, manage specific medical conditions, or optimize their chances of conception. This application assists users in finding the most suitable contraceptive method while promoting a healthy, stress-free lifestyle [22].

The primary objective of this study is to assess the software product quality (SPQ) of three mobile applications, namely *MyContraception*, *MaGrossesse*, and *Mamma&Baby*, utilizing the ISO/IEC 25010 software quality standard. This investigation centers on analyzing the impact of specific requirements on the SPQ of these applications, focusing on identifying and exploring common requirements to facilitate the development of mobile applications that effectively support and simplify the pregnancy journey for women. Moreover, the significance of this research extends to its potential to benefit various stakeholders, including patients, care providers, health application developers, health policymakers, and researchers. For patients, evaluating these mobile apps can improve access to high-quality reproductive health services, enhancing communication with healthcare providers and facilitating self-management during pregnancy and postpartum. Care providers can benefit from recommendations derived from SPQ assessments, enabling them to select and recommend effective tools to support patient care. Health application developers can use the findings to enhance the usability and effectiveness of their applications, thereby enhancing the user experience and health outcomes. Additionally, insights from this research can inform policymakers in developing regulations and guidelines to safeguard the safety, privacy, and quality of health applications. Lastly, researchers can utilize the results to advance knowledge in mobile health technology, guiding future research and innovation endeavors. To achieve these objectives, four research questions (RQs) have been formulated to analyze the SPQ of the three applications, as described in Table 1.

This article is structured as follows. Section 2 presents an overview of the method employed and describes the findings. The discussion of these findings is expounded upon in Section 3. Lastly, Section 4 provides conclusions and proposes directions for future research.

2. Methods

This study employed a structured approach comprising multiple phases and a three-step analysis process to assess SPQ and its implications for mobile applications concerning contraception, prenatal, and postnatal care.

2.1 Extracting Characteristics and Sub-characteristics from the SPQ and Quality in Use Models

The initial phase entailed extracting the characteristics and sub-characteristics from the SPQ and quality in use (QIU) models. This step established a foundational understanding of the key dimensions of software quality and usability pertinent to the study domain.

2.1.1 ISO/IEC 25010 Quality Model

The software product quality requirements and evaluation (SQuaRE) family of international standards encompasses ISO/IEC 25010, which was introduced in 2011 as a successor to ISO/IEC 9126. While ISO/IEC 9126 was technically revised and republished in 2001, it remains an international standard for specifying and evaluating SPQ [23].

Table 1. Research questions (RQs).

Research question	Motivation
RQ 1. What is the impact of pregnancy monitoring, newborn care, and contraception mobile application requirements on the software product quality software product quality (SPQ)?	To examine the effect of mobile applications for pregnancy monitoring, newborn care, and contraception on the SPQ.
RQ 2. What are the requirements that have a significant impact on SPQ?	To determine the key features of the three applications that have the greatest effect on the SPQ.
RQ 3. What are the other features that should be added to the three applications?	To identify areas in need of improvement to achieve a high-quality product.
RQ 4. What are the common features among the three applications?	Emphasize the common features in mobile applications of the same type.

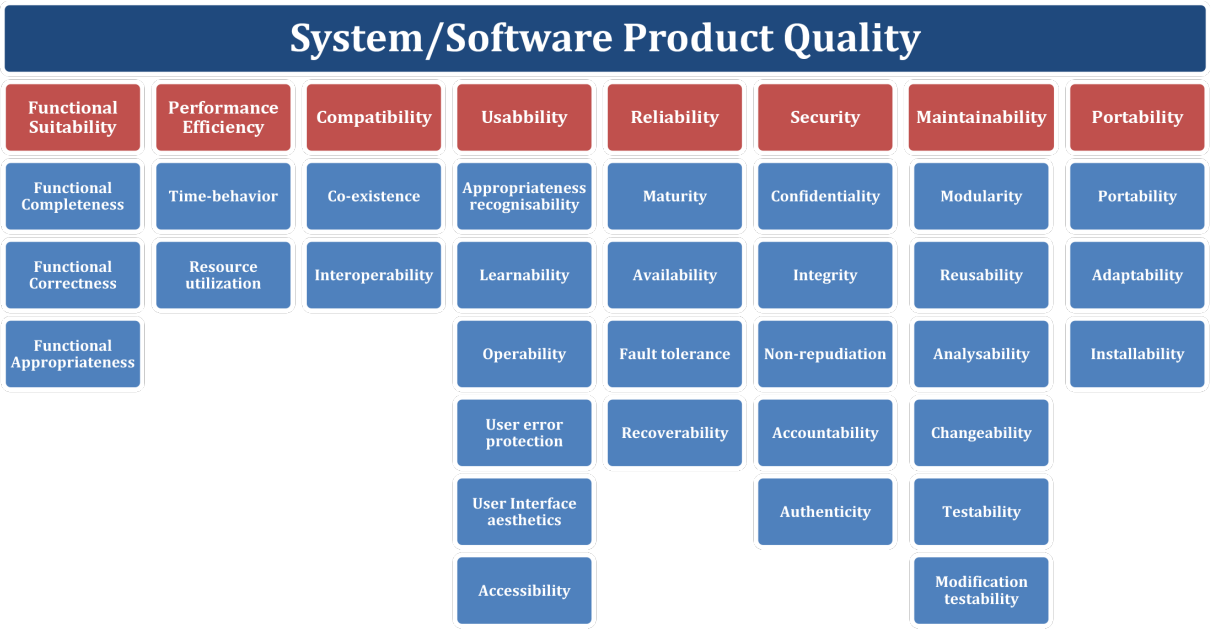

Fig. 1. Characteristics and Sub-characteristics of the SPQ Model [24].

The standard specifies two models: the SPQ and QIU models. The SPQ model focuses on the quality of the product and encompasses eight characteristics [24]. These characteristics are depicted in Fig. 1 (Ref. [24]), along with their corresponding sub-characteristics. Conversely, the QIU model pertains to the quality of the product when utilized by its intended users and comprises five characteristics [24]. Fig. 2 (Ref. [24]) provides an overview of the characteristics and sub-characteristics of the QIU model.

Some characteristics are further divided into sub-characteristics related to the outcomes of utilizing the product within specific contexts of use [24].

ISO 25010: A valuable framework for enterprise software teams to design and deliver successful software solutions. This standard divides SPQ into various sub-aspects, allowing developers to devise customized metrics and measurements to evaluate functional and non-functional requirements precisely [24].

2.1.2 ISO/IEC 25023: Assessment of System and SPQ

ISO/IEC 25023:2016, part of the SQuaRE standard series, provides metrics for assessing the quality of systems and software products. It is based on characteristics and sub-characteristics defined in ISO/IEC 25010 [25].

2.2 Description of Requirements for Contraception, Prenatal, and Postnatal Mobile Applications

Next, detailed requirements for mobile applications regarding contraception, prenatal care, and postnatal care were meticulously described. These requirements encompassed functionalities and features crucial for meeting users' needs throughout various stages of pregnancy and childcare.

This section summarizes essential requirements for pregnancy monitoring and childcare applications based on findings from previous research papers. In a previous study [19], a set of common features for mPHRs (mobile personal health records: a digital application or a platform ac-

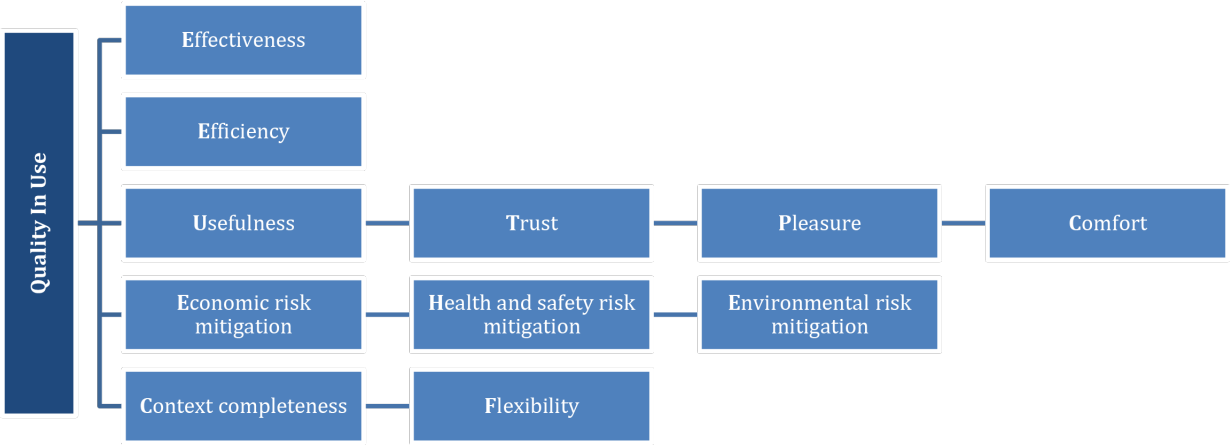

Fig. 2. Characteristics and sub-characteristics of the quality in use (QIU) model [24].

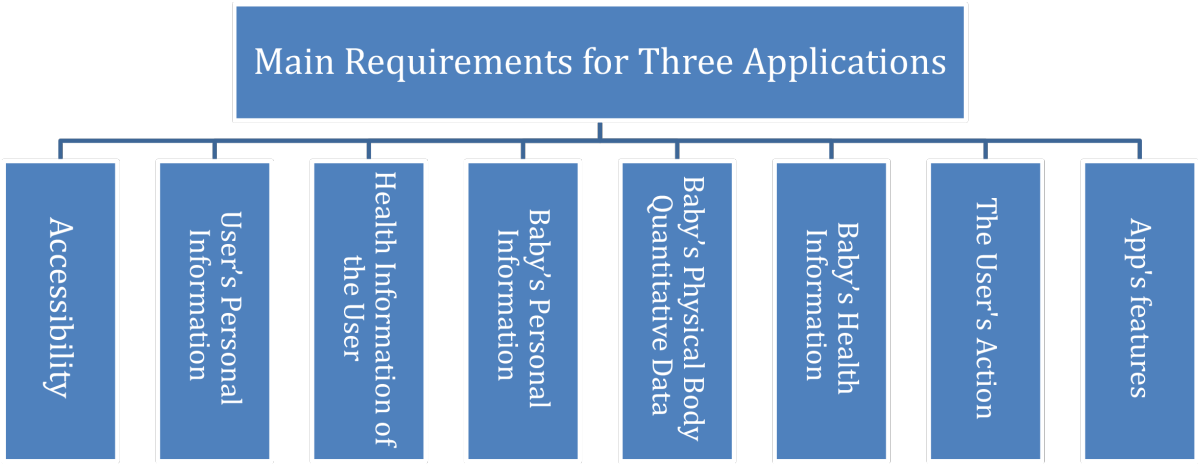

Fig. 3. Main requirements for pregnancy monitoring and childcare applications.

cessible via mobile devices that allows individuals to manage and access their personal health information) was identified to improve contraceptive fit. Additionally, further features were extracted from the same study [19], where the review and analysis assessed functionalities and technical characteristics of mobile health applications for postnatal care [26]. These studies outlined a pregnancy monitoring application's functional and non-functional requirements [27,28].

The main requirements for pregnancy monitoring and childcare mobile applications have been grouped into eight categories, as depicted in Fig. 3, each with sub-requirements detailed in the Appendix Table 3. The primary objective of these requirements is to establish a checklist for evaluating how each predefined requirement influences the external sub-characteristics of the product quality model, as outlined in the Appendix Table 4.

2.3 Analysis Process: Analyzing the Impact of Pregnancy Monitoring, Child Care, and Contraception Mobile Applications

This section outlines the methodology utilized to assess the impact of requirements on the SPQ of three mobile applications. The methodology follows a three-step approach based on previous research [29], which applied the ISO/IEC 25010 standard to mPHR. The primary aim of this analysis is to address the RQs by providing sample calculations.

2.3.1 Step 1. The Analysis of the Sub-characteristics and Characteristics of the ISO/IEC 25010 Standard for SPQ

To assess the SPQ, we utilized the ISO/IEC 25010 standard, requiring a thorough examination of the definitions of external SPQ characteristics and sub-characteristics. Additionally, we employed ISO/IEC 25023 in tandem with ISO/IEC 25010 to conduct a quantitative evaluation of SPQ in relation to its characteristics and sub-characteristics [24].

2.3.2 Step 2. Checklist of ISO/IEC 25010 SPQ Model Requirements for Pregnancy Monitoring, Newborn Care, and Contraception Mobile Applications

We have developed a checklist (as illustrated in the Appendix Table 4) to assess how each predetermined requirement influences the external sub-characteristics of the product quality model. If the variables utilized to calculate the external metric are affected by at least one requirement, it is concluded that this requirement influences the SPQ sub-characteristic.

2.3.3 Step 3. Calculation of the Degree of Impact of Pregnancy Monitoring, Newborn Care, and Contraception Mobile Applications' Requirements on SPQ

In Step 3, we calculate the degree of impact of requirements for pregnancy monitoring, newborn care, and contraception mobile applications on the SPQ. This process entails categorizing the calculated impact degrees into three categories:

$$\mathrm{ID(EC, B)} = \frac{\sum \mathrm{ID(EC, B)}}{\mathrm{N(R)}}$$

This equation quantifies the degree of influence that a block of requirements (B) has on an external quality characteristic (EC), represented as ID(EC,B).

Where:

• N(R) represents the total number of requirements in block B.

$$\mathrm{ID(EC, R)} = \frac{\mathrm{N(\ EsC, R)}}{\mathrm{N(EsC)}}$$

This formula quantifies the degree of influence that a specific requirement (R) has on an external quality characteristic (EC), referred to as ID(EC, R).

Where:

• N(EsC, R) represents the number of sub-characteristics of EC influenced by requirement R.

• N(EsC) denotes the total number of sub-characteristics of EC.

$$\mathrm{ID(EsC, B)} = \frac{\sum \mathrm{ID(EsC, R)}}{\mathrm{N(R)}}$$

This equation assesses the extent to which a block of requirements (B) affects an external sub-characteristic (EsC), denoted as ID(EsC, B).

Where:

• N(EsC, R) denotes the number of sub-characteristics of EC influenced by requirement R.

• N(R) represents the total number of requirements in block B.

The values of N(R) and N(EsC) are determined using the checklist established in Step 2 (in the Appendix Table 4). Subsequently, each impact degree is categorized into one of five groups, from very high to very low, as outlined in Table 2.

Table 2. Impact degrees and classification group.

Impact degree	Classification group
[0.9, 1]	Very high
[0.7, 0.89]	High
[0.4, 0.69]	Moderate
[0.2, 0.39]	Low
[0, 0.19]	Very low

An illustrative example shows the calculation of the impact degree of the postnatal mobile application features (POF) block of requirements on functional suitability (FS). This block encompasses nineteen FS requirements. Initially, the impact level of each requirement within the POF block on FS is established using the equation:

$$\mathrm{ID(FS, POF)} = \sum_{i=1}^{i=19} (\mathrm{ID(FS, POFi)})/19$$

Referring to the Appendix Table 4, it is observed that requirements POF6 to POF17 exclusively affect the Appropriateness sub-characteristic, with respective impact degrees of:

$$\begin{aligned}\mathrm{ID(FS, POF6)} &= \mathrm{ID(FS, POF7)} = \mathrm{ID(FS, POF9)} \\ &= \mathrm{ID(FS, POF10)} = \mathrm{ID(FS, POF12)} \\ &= \mathrm{ID(FS, POF13)} = \mathrm{ID(FS, POF14)} \\ &= \mathrm{ID(FS, POF16)} = \mathrm{ID(FS, POF17)} = \frac{1}{2}\end{aligned}$$

The remaining requirements impact both the appropriateness and accuracy sub-characteristics, as indicated by the following values of impact degrees:

$$\begin{aligned}&\mathrm{ID(FS, POF1)} = \mathrm{ID(FS, POF2)} = \mathrm{ID(FS, POF3)} \\ &= \mathrm{ID(FS, POF4)} = \mathrm{ID(FS, POF5)} = \mathrm{ID(FS, POF8)} \\ &= \mathrm{ID(FS, POF11)} = \mathrm{ID(FS, POF15)} = \mathrm{ID(FS, POF18)} \\ &= \mathrm{ID(FS, POF19)} = \frac{2}{2} = 1\end{aligned}$$

Thus, the overall impact degree of the entire block of POF requirements on FS is as follows:

$$\begin{aligned}\mathrm{ID(FS, POF)} = (&1 + 1 + 1 + 1 + 1 + 0.5 + 0.5 + 1 + 0.5 \\ &+ 0.5 + 1 + 0.5 + 0.5 + 0.5 + 1 + 0.5 + 0.5 \\ &+ 1 + 1)/19 = 0.76\end{aligned}$$

Conversely, the impact degree of the POF block on the accuracy sub-characteristic (Ac) has been calculated using the following equation:

$$\mathrm{ID(Ac, POF)} = \sum_{i=1}^{i=19} \mathrm{ID(Ac, POFi)}/19$$

According to the checklist, all requirements affect the appropriateness sub-characteristic (Ap). Thus,

$$\begin{aligned}
&\mathrm{ID(Ac, POF1)} = \mathrm{ID(Ac, POF2)} = \mathrm{ID(Ac, POF3)} \\
&= \mathrm{ID(Ac, POF4)} = \mathrm{ID(Ac, POF5)} = \mathrm{ID(Ac, POF6)} \\
&= \mathrm{ID(Ac, POF7)} = \mathrm{ID(Ac, POF8)} = \mathrm{ID(Ac, POF9)} \\
&= \mathrm{ID(Ac, POF10)} = \mathrm{ID(Ac, POF11)} = \mathrm{ID(Ac, POF12)} \\
&= \mathrm{ID(Ac, POF13)} = \mathrm{ID(Ac, POF14)} = \mathrm{ID(Ac, POF15)} \\
&= \mathrm{ID(Ac, POF16)} = \mathrm{ID(Ac, POF17)} = \mathrm{ID(Ac, POF18)} \\
&= \mathrm{ID(Ac, POF19)} = 1
\end{aligned}$$

Therefore:

$$\begin{aligned}
\mathrm{ID(Ac, POF)} = (&1+1+1+1+1+1+1+1+1+1 \\
&+1+1+1+1+1+1+1+1+1 \\
&+1)/19 = 1
\end{aligned}$$

Referring to the classification of impact degrees shown in Table 2, it is evident that the impact of the POF requirements block on FS ID(FS, POF) is categorized as high. In contrast, the impact degree of this block on the Accuracy sub-characteristic ID(Ac, POF) is classified as very high.

3. Results

This section presents the results of the impact analysis conducted on requirements for pregnancy monitoring, postnatal care, and contraception mobile applications aimed at addressing the primary RQs outlined in the introduction of this article. The analysis assesses the influence of these requirements on the SPQ characteristics.

The checklist (Appendix Table 4) encompasses 66 requirements for the three reproductive healthcare domains (pregnancy monitoring, postnatal care, and contraception) and 30 external quality sub-characteristics.

3.1 Impact of MyContraception, Mamma&Baby, and MaGrossesse Applications' Requirements on SPQ Characteristics

This section examines the influence of requirements for the *MyContraception*, *Mamma&Baby*, and *MaGrossesse* applications on SPQ characteristics.

The Appendix Fig. 10 presents the impact of each requirement for the *MyContraception* mobile application on external quality characteristics. Notably, FS is affected by all requirements, while operability is influenced by 95% of them. Performance efficiency and security are impacted by 87% and reliability by 85%. Maintainability is affected by 74% of requirements, while transferability and compatibility are influenced by only 10% and 8% of requirements, respectively. Among the requirements, user's action (UA1) has the most significant impact on SPQ, followed by personal information (PD): PD1, PD2, PD3, PD4, and contraception features (CF5), whereas app's accessibility (AA3) has the least impact on SPQ characteristics.

The Appendix Fig. 11 displays the impact of each requirement on the external characteristics of the "*Mamma&Baby*" postnatal care mobile app. FS is affected by all requirements, and 97% impacts operability. Performance efficiency, reliability, and maintainability are influenced by 92%, 90%, and 84% of requirements, respectively. Security is affected by 65% of requirements, compatibility by 35%, and transferability by 6%. UA1 significantly affects SPQ, followed by POF19, while AA3 has the least impact on SPQ characteristics.

The Appendix Fig. 12 illustrates how each requirement influences the external characteristics of the prenatal care mobile application *MaGrossesse*. FS is impacted by all requirements, with 95% affecting operability. Performance efficiency and reliability are influenced by 88% and 85% of requirements, respectively. Security is impacted by 76% of requirements, maintainability by 75%, compatibility by 17%, and transferability by 10%. UA1 has the most significant impact on SPQ, followed by prenatal features (PF5), while AA3 has the weakest impact on external quality characteristics.

Fig. 4 illustrates the impact of requirements for pregnancy monitoring, postnatal care, and contraception mobile applications on the SPQ characteristics. The findings reveal that FS is the characteristic most significantly affected by the requirements, followed by operability, performance efficiency, and reliability. Conversely, transferability is the characteristic least influenced by the requirements.

3.2 Impact of Requirement Blocks on External Characteristics and Sub-characteristics

This section explores the combined impact of requirement blocks on external characteristics and sub-characteristics pertinent to SPQ. It investigates how various requirement blocks influence critical aspects.

Fig. 5 shows that all requirement blocks affect the appropriateness, ease of use, appropriateness recognizability, and technical accessibility sub-characteristics. However, among the transferability sub-characteristics (portability, adaptability, and installability), only the app's accessibility (AA) block of requirements has an effect, while the others do not impact these aspects. Additionally, confidentiality, a security sub-characteristic, experiences a significant impact. Both the prenatal features (PF) and user's actions (UA) blocks equally influence the interoperability sub-characteristics. Concerning the operability characteris-

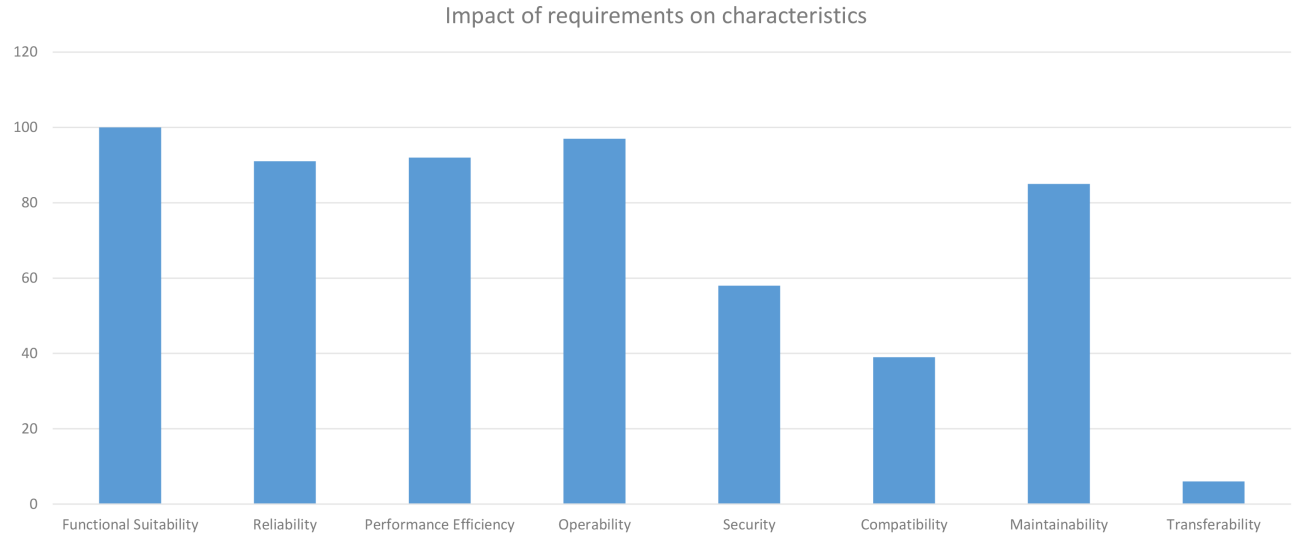

Fig. 4. Impact of all requirements on the SPQ characteristics.

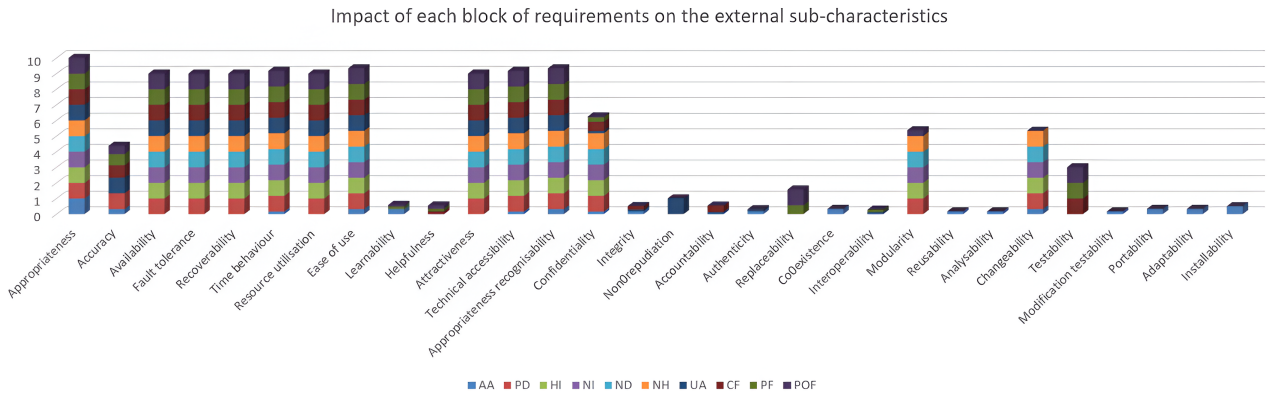

Fig. 5. The impact of requirement blocks on the external sub-characteristics of SPQ. AA, accessibility; PD, user's personal information; HI, user's health information; NI, baby's personal information; ND, baby's physical body quantitative data; NH, baby's health information; UA, user's action; CF, contraception mobile application features; PF, prenatal mobile application features; POF, postnatal mobile application features.

tic, ease of use, technical accessibility, and appropriateness recognizability are the highly impacted sub-characteristics across all requirement blocks. Except for AA, all requirement blocks affect the sub-characteristics of reliability.

The Appendix Fig. 13 demonstrates that the personal information (PD) block has the most substantial impact on SPQ. Among the eight quality characteristics, security and transferability are least affected by the requirement blocks owing to their lower degrees of influence. Notably, all requirements, excluding AA, significantly affect reliability, whereas only block AA influences transferability.

Fig. 6 illustrates the influence of the requirements for the three applications on the 30 external quality sub-characteristics. As depicted, appropriateness is the most impacted sub-characteristic, followed by fault tolerance, time behavior, availability, ease of use, recoverability, appropriateness recognizability, and resource utilization. Conversely, sub-characteristics such as learnability, helpfulness, integrity, coexistence, interoperability, reusability, analyzability, portability, adaptability, and installability are least affected by the requirements.

4. Discussion

This section discusses the study's findings, which focused on the requirements of three reproductive healthcare mobile applications: *MaGrossesse*, *MyContraception*, and *Mamma&Baby*. The requirements were extracted, refined, and organized based on relevant studies in the three reproductive healthcare domains.

The SPQ of the three applications was evaluated by analyzing the impact of the specified requirements on eight quality characteristics and their related sub-characteristics, as defined in the ISO/IEC 25010 model and ISO/IEC 25023 standard. As detailed in Appendix Table 3, three require-

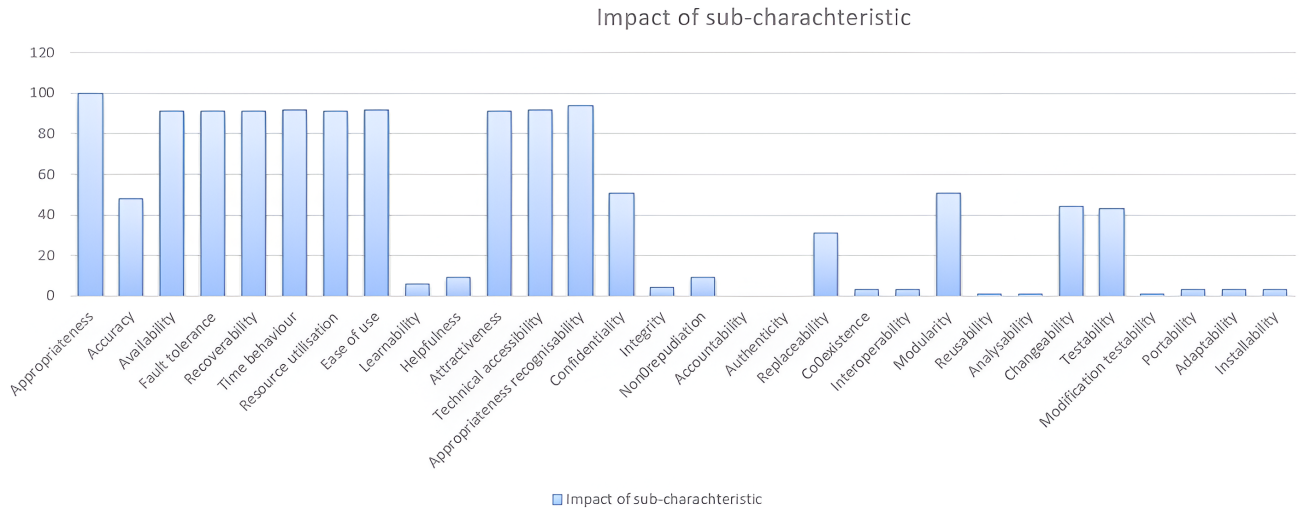

Fig. 6. The impact of requirements on external sub-characteristics.

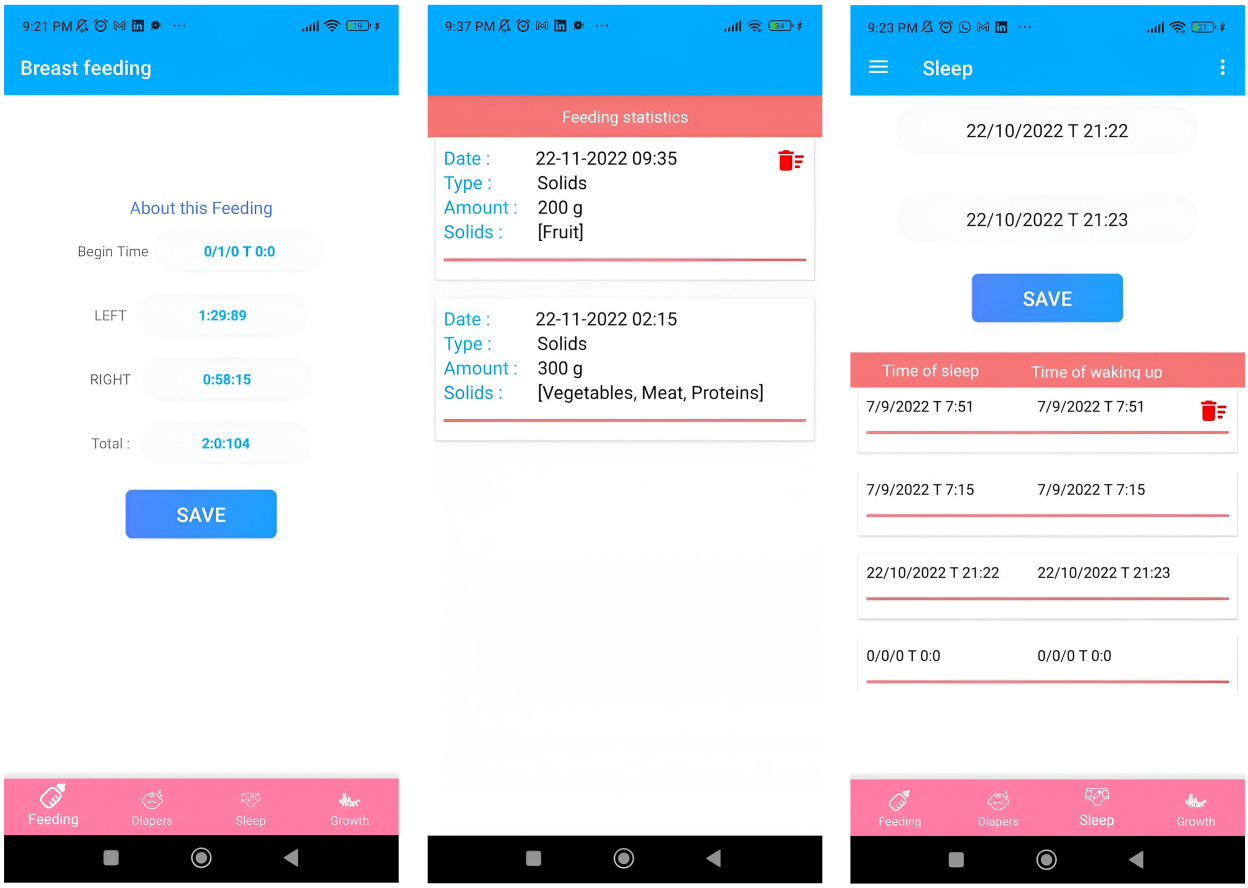

Fig. 7. Screenshots of the Mamma&Baby mobile application.

ments were identified to define those related to each domain of the three reproductive healthcare: prenatal, contraception, and postnatal. To determine the extent to which each requirement affects the external quality attributes, the analysis process outlined in section 3.1 was applied to all requirements categorized as SPQ requirements, except for the operating system (OS) app's accessibility (AA): version (AA2) and cost (AA3). Data analysis and the generation of graphics were conducted using the Statistical Package for the Social Sciences software version 22.2 (SPSS Statistics 22.0, IBM Corp, Armonk, NY, USA)

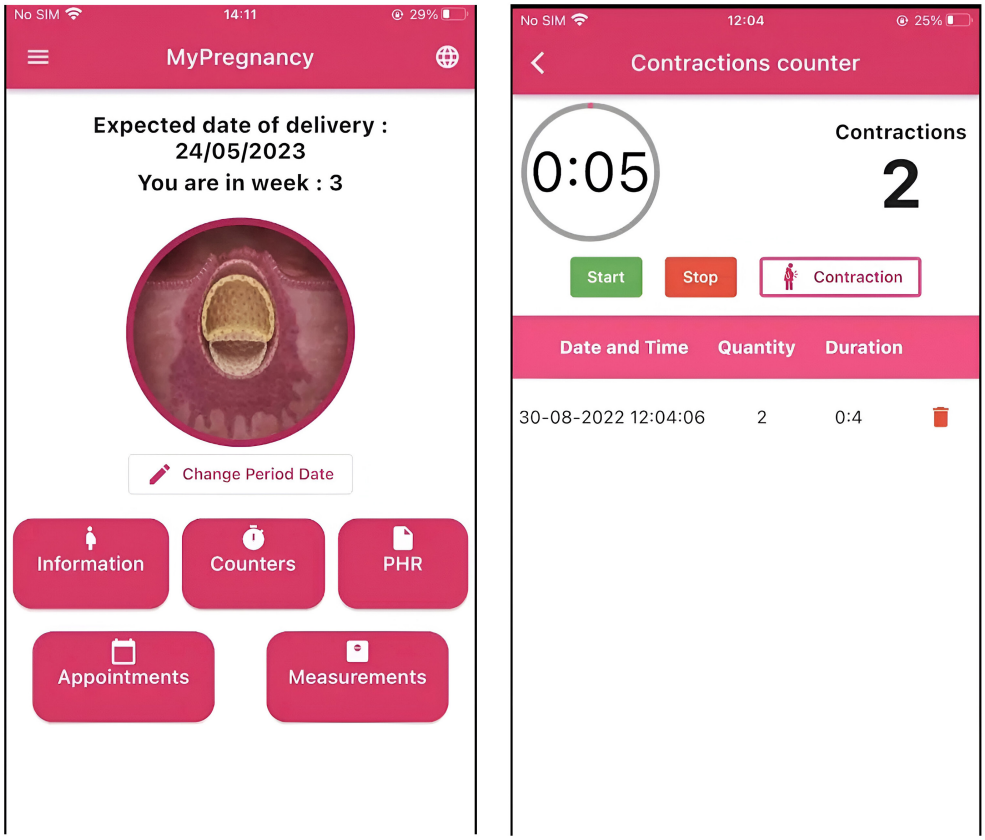

Fig. 8. Several screenshots of the MaGrossesse mobile application.

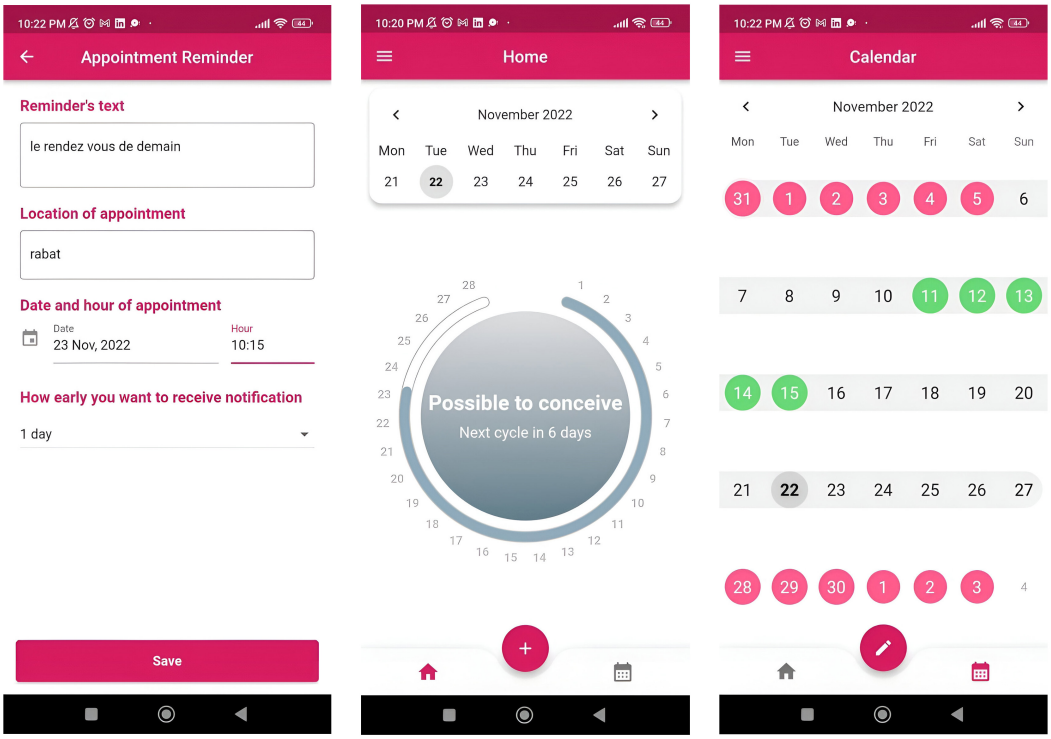

Fig. 9. Screenshots of the MyContraception mobile application.

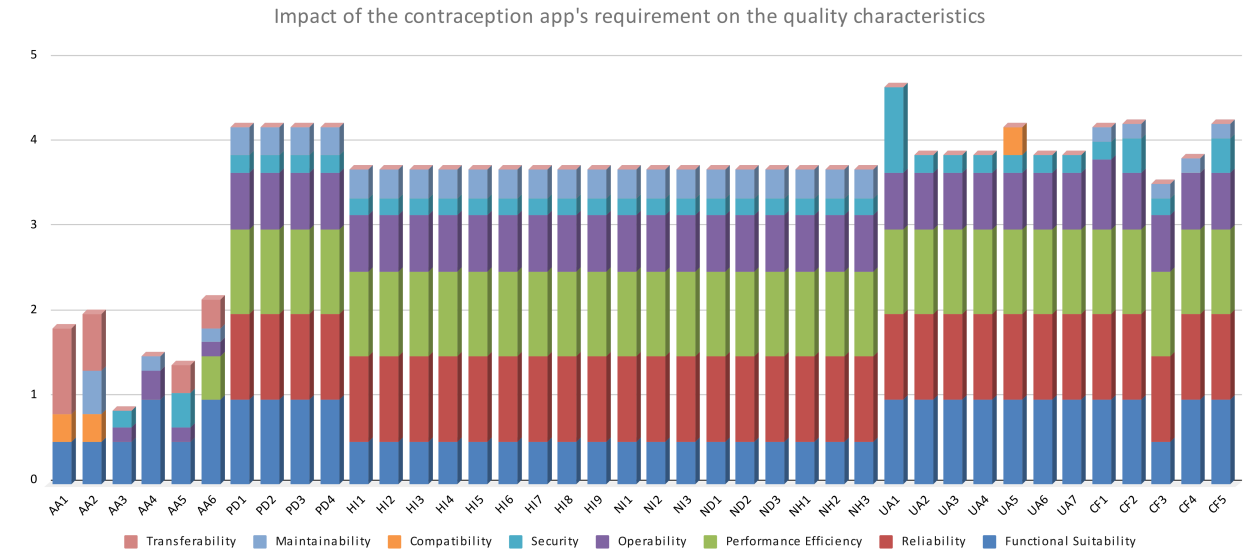

Fig. 10. The influence of the requirements for the contraception application on the characteristics of SPQ.

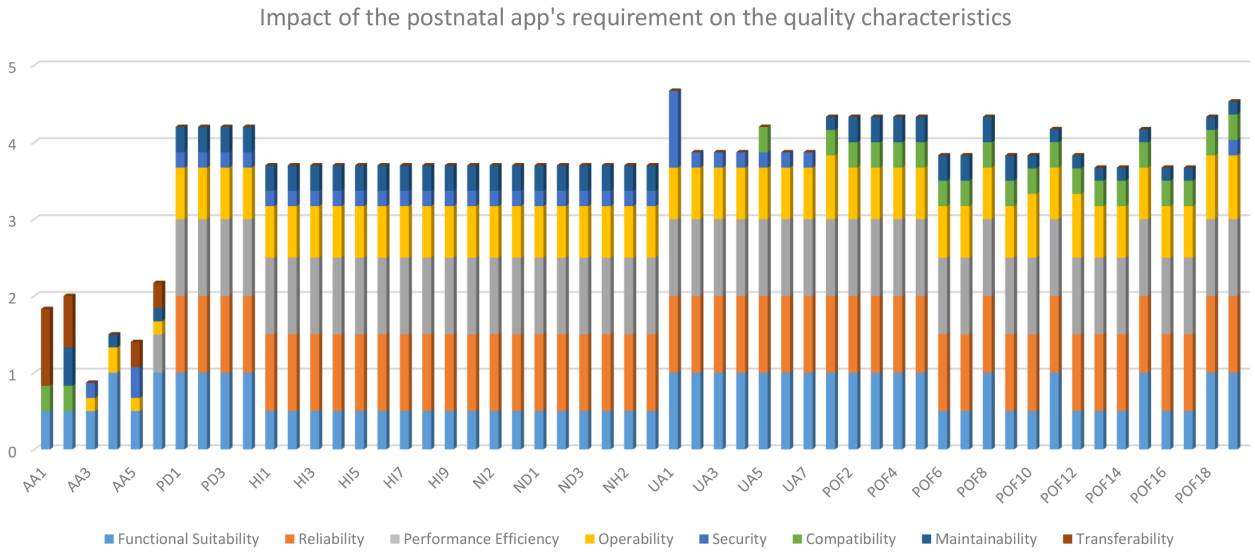

Fig. 11. The effect of the requirements for the postnatal application on the characteristics of SPQ.

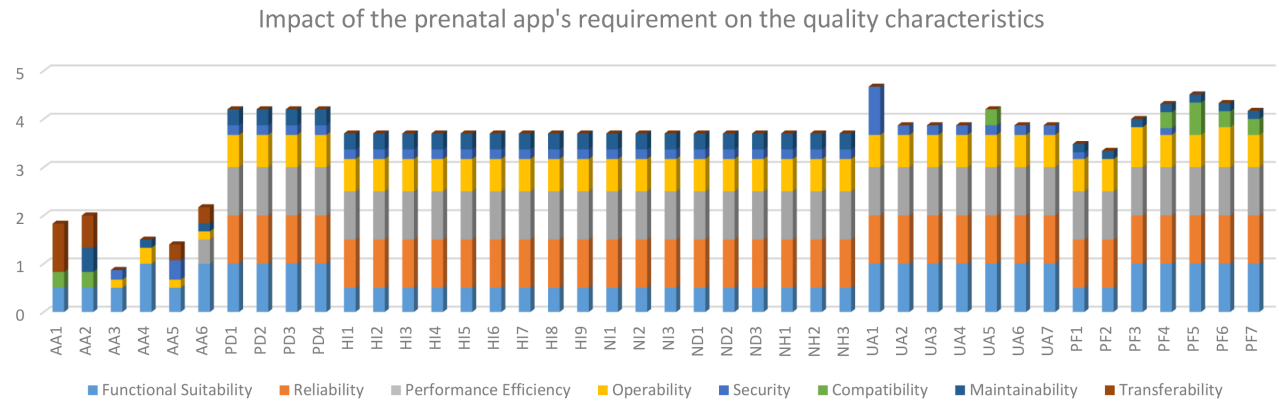

Fig. 12. The influence of the requirements for the prenatal application on the characteristics of SPQ.

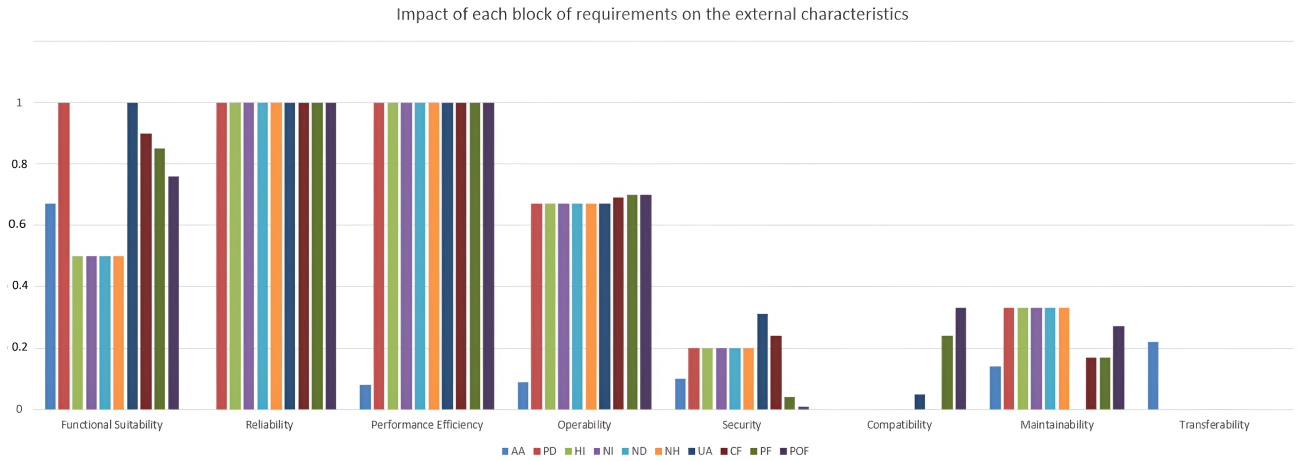

Fig. 13. The impact of the requirements block on the external characteristics of SPQ.

4.1 RQ 1. What is the Impact of Pregnancy Monitoring, Newborn Care, and Contraception Mobile Application Requirements on the Software Product Quality SPQ?

After completing the impact analysis, it was revealed that blocks PD, PF, and POF significantly influenced SPQ characteristics. There has been a considerable increase in the number of mobile apps related to health, offering advanced tools and services for decision-support healthcare systems based on the user's situation, particularly in the medical domain. These apps operate using implicit and explicit data collected from the user and their environment, and they store confidential information about the patient [30]. This implies the importance of implementing security [31,32] and privacy as essential non-functional requirements during mobile application development because security lapses can adversely affect stakeholders and users alike.

Beyond data security and privacy, eHealth and mHealth applications must comply with stringent regulations and standards like the Health Insurance Portability and Accountability Act (HIPAA) in the United States to ensure proper handling of patient data within legal boundaries. Ensuring SPQ is crucial for these applications to meet regulatory requirements and standards [33,34]. Therefore, prioritizing SPQ characteristics such as security, privacy, and portability in mobile health application development is imperative. By doing so, developers can guarantee adherence to the highest quality standards, instilling user trust in handling sensitive information, thereby bolstering application popularity and increasing downloads and positive reviews [29]. Additionally, frameworks like ISO9126-FRAM and Diffserv-FRAM have been developed to aid programmers, developers, and SPQ evaluators in navigating mobile environment limitations and achieve superior mobile software quality [35].

4.2 RQ 2. What are the Requirements that Have a Significant Impact on SPQ?

Regarding the application features, the integrated social network for mothers to support each other and exchange experiences and issues (POF19) within the postnatal application is the requirement with the most significant impact on SPQ (Fig. 5, and Appendix Figs. 11,13). Previous studies suggest that individuals utilizing social media platforms benefit from health recommendation services for minor issues, particularly busy individuals who favor it over in-person consultations, which may lead to misdiagnoses [36,37]. A mobile discussion forum is particularly intriguing, notably within pregnancy monitoring and childcare applications [38,39]. This in-application open discussion space presents an opportunity for pregnant women and new mothers to ask questions, discuss potential fears and concerns regarding their pregnancy or postnatal period, and share experiences to receive real-time guidance during moments of uncertainty.

FS, the characteristic most affected by these requirements, ensures that applications meet user expectations, provide expected results, and offer features such as ease of use and reliability. Extensive research has been conducted to identify effective approaches for evaluating critical characteristics like functional suitability and usability outlined in ISO/IEC 25010 [40,41]. These findings have led to the development of comprehensive evaluation methodologies, procedures, and toolkits facilitating thorough assessments of functional suitability [42–44].

Fig. 4 shows that operability is the second most impacted characteristic by these requirements across all three applications. Its significance lies in enhancing user engagement, satisfaction, health outcomes, and application adoption rates while minimizing errors. The usability of health applications is paramount for users to achieve their objectives, as highlighted in various studies [38–40]. Additionally, Fig. 4 underscores the considerable influence of requirements on performance efficiency and reliability,

Table 3. Requirements and sub-requirements for mobile applications.

Category	Requirement
	Accessibility (AA)
AA1	Type of operating system (OS)
AA2	OS version compatibility
AA3	Cost: free or paid
AA4	Language options
AA5	Target audience: (in our case, women)
AA6	Internet accessibility: (whether the application needs an online connection)
	User's personal information (PD)
PD1	User's full name
PD2	User's date of birth
PD3	User's email address
PD4	User's phone number
	User's health information (HI)
HI1	Illness history
HI2	Blood group
HI3	Psychological disorders
HI4	Emotional disorders
HI5	Type of delivery
HI6	Number of childbirths
HI7	Family illness history
HI8	Vaccines
HI9	Contraceptive method
	Baby's personal information (NI)
NI1	Full name
NI2	Gender
NI3	Date of birth
	Baby's physical body quantitative data (ND)
ND1	Weight
ND2	Height
ND3	Head circumference
	Baby's health information (NH)
NH1	Sleep duration
NH2	Vaccines
NH3	Blood group
	User's action (UA)
UA1	Authentication
UA2	Creating information
UA3	Updating and modifying information
UA4	Deleting information
UA5	Uploading image
UA6	Sharing information
UA7	Backup data
	Contraception mobile application features (CF)
CF1	Provides advice on contraceptive options based on World Health Organization (WHO)'s guidelines
CF2	Helps determine the best contraception method based on individual needs
CF3	Offers personalized information and reminders for contraception
CF4	Tracks menstrual cycle, fertility window, contraceptive use, and symptoms
CF5	Manages medical history, appointments, analysis, and notes in one application
	Prenatal mobile application features (PF)
PF1	Access medical health records
PF2	Maintain awareness of health
PF3	Receive guidance throughout pregnancy months
PF4	Schedule medical appointments with physicians
PF5	Monitor pregnancy development
PF6	Track contractions and baby kicks
PF7	Record weight and blood pressure measurements
	Postnatal mobile application features (POF)
POF1	Feeding (bottles, meals, etc) management
POF2	Sleep cycle management
POF3	Diaper changes
POF4	Growth (height, weight)
POF5	Personalized medical follow-up reminders/vaccines
POF6	History of medical appointments
POF7	Vaccines calendar
POF8	Vaccines follow-up
POF9	Postpartum depression quick screen
POF10	Concise information on postpartum mental disorders
POF11	Treatment strategies
POF12	Postpartum weight management
POF13	Utilize visual aids for exercises
POF14	Postpartum diet
POF15	Guide your baby's development by month
POF16	Tips on breastfeeding and baby hygiene
POF17	Warning signs for mothers and babies
POF18	Comprehensive frequently asked questions
POF19	An integrated social network for moms to help each other and share experiences

which are pivotal for ensuring a positive user experience, building trust, driving revenue, and maintaining competitiveness in the mobile application market. The research underscores the importance of considering reliability and efficiency in software quality assessments, especially concerning products designed for mobile platforms [45]. A study conducted on 115 organizations in Italy confirmed that during crisis conditions, information technology (IT) performance is significantly affected by usage reliability and support service reliability [46].

Fig. 4 and Appendix Fig. 13 show that efficient performance is also important, aiding in minimizing battery usage, processing sensitive data quickly and securely, and delivering timely and accurate information to users. Various factors contribute to the efficient performance of a mobile app, including optimizing code by adhering to programming best practices (commenting code, minimizing duplications, utilizing design patterns, etc.), reducing network requests, efficient memory usage, battery optimization, as well as rigorous testing and debugging [46–48]. The efficient performance of a mobile application is gauged by its speed, responsiveness, and resource utilization, all pivotal for ensuring a positive user experience.

4.3 RQ 3. What are the Other Features that should be Added to the Three Applications?

According to Appendix Figs. 10,11,12, and Fig. 4, transferability and compatibility are the characteristics least

Table 4. Checklist for assessing the impact of requirements for pregnancy monitoring and childcare applications on software product quality characteristics.

Requirements	Functional suitability		Reliability			Performance efficiency			Operability					Security					Compatibility			Maintainability						Transferability		
	Appropriateness	Accuracy	Availability	Fault tolerance	Recoverability	Time behavior	Resource utilization	Ease of use	Learnability	Helpfulness	Attractiveness	Technical accessibility	Appropriateness recognizability	Confidentiality	Integrity	Non-repudiation	Accountability	Authenticity	Replaceability	Co-existence	Interoperability	Modularity	Reusability	Analyzability	Changeability	Testability	Modification testability	Portability	Adaptability	Installability
AA1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	1	1
AA2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	1	1	-	1	1	-
AA3	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
AA4	1	1	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
AA5	1	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
AA6	1	1	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1
PD1	1	1	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
PD2	1	1	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
PD3	1	1	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
PD4	1	1	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
HI1	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
HI2	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
HI3	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
HI4	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
HI5	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
HI6	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
HI7	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
HI8	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
HI9	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
NI1	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
NI2	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
NI3	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
ND1	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
ND2	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
ND3	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
NH1	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
NH2	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
NH3	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
UA1	1	1	1	1	1	1	1	1	-	-	1	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-
UA2	1	1	1	1	1	1	1	1	-	-	1	1	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
UA3	1	1	1	1	1	1	1	1	-	-	1	1	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
UA4	1	1	1	1	1	1	1	1	-	-	1	1	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
UA5	1	1	1	1	1	1	1	1	-	-	1	1	1	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-
UA6	1	1	1	1	1	1	1	1	-	-	1	1	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
UA7	1	1	1	1	1	1	1	1	-	-	1	1	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
CF1	1	1	1	1	1	1	1	1	-	1	1	1	1	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-

Table 4. Continued.

Requirements	Functional suitability		Reliability			Performance efficiency			Operability							Security				Compatibility			Maintainability					Transferability			
	Appropriateness	Accuracy	Availability	Fault tolerance	Recoverability	Time behavior	Resource utilization	Ease of use	Learnability	Helpfulness	Attractiveness	Technical accessibility	Appropriateness recognizability	Confidentiality	Integrity	Non-repudiation	Accountability	Authenticity	Replaceability	Co-existence	Interoperability	Modularity	Reusability	Analyzability	Changeability	Testability	Modification testability	Portability	Adaptability	Installability
CF2	1	1	1	1	1	1	1	1	-	-	1	1	1	1	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-
CF3	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
CF4	1	1	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
CF5	1	1	1	1	1	1	1	1	-	-	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
PF1	1	-	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
PF2	1	-	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
PF3	1	1	1	1	1	1	1	1	-	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
PF4	1	1	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
PF5	1	1	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	1	-	1	-	-	-	-	1	-	-	-	-
PF6	1	1	1	1	1	1	1	1	1	-	1	1	1	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
PF7	1	1	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
POF1	1	1	1	1	1	1	1	1	1	-	1	1	1	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
POF2	1	1	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	1	-	-	1	-	-	-	1	-	-	-	-
POF3	1	1	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	1	-	-	1	-	-	-	1	-	-	-	-
POF4	1	1	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	1	-	-	1	-	-	-	1	-	-	-	-
POF5	1	1	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	1	-	-	1	-	-	-	1	-	-	-	-
POF6	1	-	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	1	-	-	1	-	-	-	1	-	-	-	-
POF7	1	-	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	1	-	-	1	-	-	-	1	-	-	-	-
POF8	1	1	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	1	-	-	1	-	-	-	1	-	-	-	-
POF9	1	-	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
POF10	1	-	1	1	1	1	1	1	-	1	1	1	1	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
POF11	1	1	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
POF12	1	-	1	1	1	1	1	1	-	1	1	1	1	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
POF13	1	-	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
POF14	1	-	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
POF15	1	1	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
POF16	1	-	1	1	1	1	1	1	-	1	1	1	1	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
POF17	1	-	1	1	1	1	1	1	-	-	1	1	1	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
POF18	1	1	1	1	1	1	1	1	-	1	1	1	1	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
POF19	1	1	1	1	1	1	1	1	1	-	1	1	1	1	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
Imp. SC (%)	100	48	91	91	91	92	91	92	6	9	91	92	94	51	4	9	0	0	31	3	3	51	1	1	44	43	1	3	3	3
Imp. C (%)	100		91			92			97							58			39			85					6			

Imp. SC, Impact Sub Characteristic; Imp. C, Impact Characteristic.

impacted by requirements. Ensuring transferability and compatibility is crucial for guaranteeing application accessibility, functionality, and positive user experiences.

To ensure transferability in health applications, developers can adopt standard data formats compatible with multiple platforms, such as the Health Level Seven International (HL7) standard for EHRs [49–52]. Additionally, employing cloud-based storage solutions allows users to access their data from any internet-connected device [53–55].

To ensure compatibility, developers can adhere to standard coding practices and utilize programming languages compatible with multiple platforms, such as JavaScript, Dart, Xamarin, and Kotlin [56–58]. Thorough testing on various devices and operating systems is essential to ensure proper functionality across all platforms [59–62]. Furthermore, employing responsive design techniques ensures that the app's user interface and features adapt seamlessly to different screen sizes and resolutions.

Significant security flaws have been identified regarding the reform of the authentication mechanism (UA4) of a system, as shown in the Appendix Figs. 11,13 and Fig. 5. Additional security measures are being proposed to enhance user credential security to rectify these flaws. Options include implementing secure questions, smart card technology, or biometric verification, each offering distinct benefits to bolster user information protection and thwart unauthorized access, thereby safeguarding confidential data [63].

Applications need to provide useful features and secure their users' data. A blockchain and Distributed Ledger-based Improved Biomedical Security system (BDL-IBS) has been proposed in a previous study [64] as a means to enhance privacy and security in healthcare. Research indicates that blockchain technology facilitates fast, easy, and secure data exchange, thereby enhancing patient privacy and security.

4.4 RQ 4. What are the Common Features among the Three Applications?

Tracking medical history can prove challenging, especially for individuals managing multiple health conditions. This entails organizing doctor's appointments, discussions, diagnostic tests, lab results, and treatment plans [65,66], underscoring the importance of this feature in mobile applications [67,68]. Across the three applications *Mamma&Baby*, *MaGrossesse*, and *Mycontraception*, a common feature emerges: the ability to track medical history contraception features (CF5) for the contraception app, prenatal features (PF1) for the prenatal app, and postnatal features (POF6) for the postnatal app, which can be considered a critical source of security vulnerabilities alongside authentication.

Reminders play a pivotal role in mobile applications by aiding users in remembering crucial tasks and events, reducing forgetfulness, enhancing user experience, boosting engagement, and improving application reliability. *Mycontraception* and *Mamma&Baby* share a common feature (CF3) and (POF5), namely the reminder feature enabling women to set alerts or notifications for vital tasks such as medication intake, appointment attendance, breastfeeding goals, or deadlines. Various reminders, including mobile phone-based interventions and patient-centered reminders, have proven effective in enhancing medication adherence and follow-up care in postnatal contraception and prenatal care settings [69–71].

This study has identified several requirements for pregnancy monitoring and childcare applications that developers and SPQ evaluators can exploit for various needs. The software development process may be followed by evaluating SPQ to deliver a high-quality, stable, and bug-free version. The SPQ requirements specification should provide quantitative descriptions of monitoring and childcare requirements for external SPQ characteristics using external measurements, subsequently serving as criteria for evaluating the requirements. The checklist utilized in this study to evaluate how pregnancy monitoring and childcare requirements impact SPQ characteristics and subcharacteristics could prove highly beneficial to developers of such mobile applications and testers of web or mobile software products, including unit testing, integration testing, and functional testing. Moreover, stakeholders can consider the concepts discussed and standards used to develop essential guidelines to enhance the overall standard of pregnancy monitoring and childcare applications.

This evaluation of the impact of requirements for three mobile applications on SPQ has been based on their initial versions, which included bugs and crashes, representing the first limitation of the study. Testing sessions conducted by computer science students involved evaluating the applications and completing app-related questionnaires containing inquiries about current functionalities, bug lists, areas for improvement, problems, and open space for general comments. While this approach yields valuable insights, the absence of end-user feedback represents another limitation. Including end-user feedback could offer additional perspectives on the practical usability and effectiveness of the evaluated mobile applications.

Based on the testing session results, the Software Project Management (SPM) team has started improving the applications, involving corrective and evolutionary maintenance and testing to achieve a stable and robust version. Other unmentioned requirements may also significantly impact the research, constituting another limitation. Though these limitations may have had a minor impact on the results, the study's findings are believed to be valuable for future research.

5. Conclusions and Future Work

This study introduced the three applications *Mamma&Baby*, *MaGrossesse*, and *Mycontraception*, utilizing them to identify 66 requirements for pregnancy

monitoring, contraception, and postnatal care. The degree of impact of these requirements was assessed using the ISO/IEC 25010 and ISO/IEC 25023 standards, which gauge SPQ. A checklist encompassed the requirements and the eight SPQ characteristics and sub-characteristics specified in the ISO/IEC 25010 standard. The findings revealed that the pregnancy monitoring and childcare requirements minimally affected certain sub-characteristics, such as transferability, compatibility, and maintainability. Nevertheless, these requirements significantly influenced the functional suitability characteristic, followed by operability, performance efficiency, reliability, and security.

This study facilitated an exploration of the four research questions outlined in Table 1, yielding the following results:

i. For RQ 1, it was concluded that privacy and security requirements significantly impacted SPQ.

ii. RQ 2 revealed that FS, operability, and efficient performance were the characteristics most affected by these requirements across the three applications.

iii. RQ 3 emphasized enhancing privacy and security by improving the system's authentication mechanism. It was suggested that native solutions be employed to ensure compatibility and transferability of the applications.

iv. Concerning RQ 4, it was found that features such as medical history tracking and reminders were present in all three applications, underscoring their crucial role in healthcare decision-making.

This research highlights the essential characteristics developers must prioritize when designing mobile applications for pregnancy monitoring, childbirth, and contraception. It is recommended to consider factors such as security, privacy, functionality, operability, and performance to ensure the development of a superior product.

Future work will focus on assessing the QIU of the three mobile applications intended for pregnancy monitoring and childcare, following the guidelines outlined in Section 2 of the ISO/IEC 25010 standard. We will use the latest versions of these mobile applications to address technical issues and enable a comprehensive comparison of evaluation results across iOS and Android platforms. Our objective is to provide a comprehensive and accurate evaluation of the quality of use of these applications, aiming to identify potential areas for improvement and offer recommendations for enhancing the user experience. Furthermore, this research will yield valuable insights into the effectiveness and efficiency of these applications in assisting users during pregnancy, contraception, and postnatal care.

Availability of Data and Materials

The data sets produced and examined during the current study, which involved a questionnaire regarding the evaluation of the applications, can be accessed in the [DataSet ISO/IEC 25010-based quality evaluation of three mobile applications for reproductive health services in Morocco] repository, with the DOI: 10.13140/RG.2.2.36225.84321.

Author Contributions

All authors participated in the conception and design of this study. Material preparation, data collection, and analysis were conducted by KM and AI, FEA. The first draft of the manuscript was written by KM and FEA, and all authors KM, AI, FEA, JL, NCB and OH provided feedback on previous versions and contributed to editorial changes in the manuscript, and have read and approved the final manuscript.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

Appendix

See Figs. 7,8,9,10,11,12,13 and Tables 3,4.

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