A Systematic Review on Usability of mHealth Applications on Type 2 Diabetes Mellitus

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Abstract In this present digital world, smart phones play a vital role, especially in the healthcare sector. The various mHealth applications installed in smart phones can solve primary health-related issues at a fingertip. However, the utility of those applications will increase if they meet user satisfaction and can solve the tasks effectively and efficiently. Thus, usability evaluation of mHealth applications is a matter of concern. Many usability evaluation techniques have been used till now but a majority of them are not unified and do not safeguard all usability aspects especially for mHealth applications. The purpose of this study is to recognize specific attributes that might help tremendously in assessing the usability of mHealth applications and examine the features of various usability evaluation methodologies for evaluating mHealth applications featured for diagnosing Type 2 diabetes mellitus (T2DM).

Keywords Usability · mHealth applications · Usability inspection and usability testing

1 Introduction

The availability and the popularity of mHealth applications have rapidly increased [1]. The intervention of mHealth applications has become an essential instrument of the public health professional and the researcher [2–4]. The development of mobile health applications for the management of the chronic diseases like diabetes is frequently taking place [5].

Type 2 diabetes mellitus (T2DM) is a kind of disease related to metabolic disorder. High levels of blood glucose are defining feature of this condition. Frequent urination, increased hunger, and thirst [6] are the common symptoms of T2DM. Self-management of diabetes involves actions that include condition handling and slowing down disease progress [7]. Self-monitoring of blood glucose (SMBG) aids in glycemic management, delays the onset of complications related to diabetes,

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and reduces the risk of hospitalizations [8]. Self-management of diabetes helps in improving one's lifestyle that includes proper exercise, a healthy diet, and adhering to medication [9].

Today, mobile applications are providing services and functionalities in the field of business, entertainment, and education and also in managing and preventing chronic diseases that include self-care of diabetes [10]. Assessment and evaluation of the usability of the mobile applications are very much important for ensuring the accuracy and utility of the mHealth apps that we use. The term "usability evaluation" refers to the process of assessing the mobile applications' usability. The evaluation of the usability of mHealth applications related to diabetes self-management is critical in assisting the patients who are diabetic in choosing the optimal mHealth application for their needs. The goal of this study is to examine and compare various usability evaluation methods (UEMs) for evaluating and assessing the usability of mHealth applications on Type 2 diabetes mellitus.

The comparison may serve as a reference that can guide the evaluators in choosing the most appropriate UEMs. The paper also aims to review the previous studies and the techniques through the systematic literature review (SLR) for the purpose of usability evaluation. This will help in selecting the usability guidelines.

This paper has been organized in the following way. Section 2 provides the related work on the usability evaluation of mHealth applications. The objective of this paper has been discussed in Sect. 3. Section 4 presents the usability attributes. Section 5 focuses on the results and analysis, and Sect. 6 concludes our work.

2 Review of Literature

Various usability evaluation methods are used to recognize usability issues and improve interface design usability. Analytical and empirical approaches are the two types of methods. Analytical methods are used for the inspection of the interface by involving usability experts. They are quick and cost-effective. On the other hand, in empirical methods, the testing involves the actual users. Table 1 shows the comparison study of various research works along with result analysis, advantages, and disadvantages. The focus of this section is on previous studies that assessed or evaluated the usability of various mHealth applications using various usability variables such as users, assessors, or software tools.

Table 1 Comparison study of usability evaluation methodologies adopted in various research works

Objective of the paper	Methodology used	Result analysis	Advantages	Limitations
The goal of this study [12] is to evaluate the usability of four diabetes applications that are intended to help patients manage their diabetes with the help of Self- Determination Theory (SDT), a health behavior theory linked to motivation and personality, for usability assessment and application design	Heuristic evaluation method: On the basis of Nielson's ten heuristics and usability satisfaction rating, experts evaluated four of the best-rated diabetes apps. Experts used a checklist for intuitive design, which was then updated for diabetes-related applications. Expert evaluators assessed the usability of seven device features, including carb consumption, exercise operation, insulin dosage, blood glucose (BG) reading, BG report, and BG report emailing. Minor, moderate, severe, and catastrophic violations have been assigned a severity rating (1–4). The SUS (System Usability Scale) was used to assess the app's usability and estimate the user's satisfaction level	• None of the four applications acquired a SUS rating related to the usability of 70 or higher. The average usability evaluation time of the application was 52 min • Total 314 heuristic evaluations were identified. 62% of the cases were extremely serious, with major or catastrophic severity ratings	• Evaluation of the four top-rated diabetes applications can improve usability • Intuitive design will help in making the applications patient-friendly. The application developers and designers can help to motivate patients and also provide education in better self-management of diabetes	• The future research should include the needs of patient training, usage barriers, and need of facilitators for use on a long-term basis • Inputs from the caregivers and the clinicians should be taken into consideration
The assessment technique in this work [13], involves the collection of usability data using a hybrid methodology and heuristic evaluation, as well as a thorough investigation of a mHealth approach for diabetes self-management	Heuristic evaluation, think-aloud, and questionnaire methods: A group of T1 diabetes patients who were using the Diabetes Monitoring (DiMo) application underwent a usability evaluation. To identify the usability issue, a hybrid strategy method combining think-aloud and post-questionnaire procedures was used. For data analysis, such as recognition, grouping, and structuring, Framework Analysis (FA), and Usability Problem Taxonomy (UPT) were used	• Each of the DiMo applications had a total of 28 consolidated issues. The Travis Criteria was then used to categorize these issues with the severity level • Study presented can be used for determining the usability level of the software applications	Usability evaluation results of the experiment can improve the tools of DiMo thereby improving essential factors such as empowerment and engagement in the monitoring of diabetes	Currently, these types of applications are rapidly expanding, and usability issues have a negative effect on device users. As a result, increased usability can lead to increased user empowerment and involvement

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Objective of the paper	Methodology used	Result analysis	Advantages	Limitations
The approaches for evaluating or assessing the content, usability, and efficiency of commercially available mHealth applications are summarized by the authors in [14]. The application features are compared using the Content Analysis	Content analyses and usability testing methods: • Analysis of the content, observational studies, usability testing, and efficiency or efficacy testing are used • Coding and interpretation of qualitative text-based content were employed in content analysis. Content analysis is done of the features, health information, and advice of the commercial health applications • Usability testing is done to see how an application functions and whether the application serves its intended purpose or not • Observational studies are done to assess the usage of the application, satisfaction, and the analytical value of application use • Efficacy testing determines a significant change in behavior and clinical results	• Three frequent comparators against which the contents of the application can be compared include clinical care guidelines, procedures based on evidence, and change in behavior or modification strategies • The application's content has been compared with clinical guidelines • Evidence-based protocols have been reported to have poor rates of strategies • Behavior change techniques involve theories related to health behavior and meta-analyses	• The application features using clinical guidelines behavior change and evidence-based protocols techniques can be compared • Usability testing can help to figure out how well the application functions and achieves its aim	• Systematic review of the applications was not conducted • Researchers should minimize delays in analysis of data, processing of data, and publication due to the rapid rate of technological progress • Evaluation of the technical functions of the application is not done
The authors of this study [15] compared the contents and features of different diabetic self-management mHealth applications. The study compares diabetes management applications in either iOS or Android	Content and features evaluation methods: • The search for mobile medical applications for diabetes is done in both the Apple iOS by using iPhone 6 and Google Android OS by using Lenovo A369i • It includes SMBG (self-monitoring of blood glucose) which helps the user in recording the measurement of blood glucose using the applications • The mobile applications are searched using a search key "diabetes"	• 35 applications were evaluated in both Apple and Google Play Store • Most applications were having features enabling the users for exporting the data files through email. Patients can store blood glucose readings and can later export them for review during their medical follow-up	According to the study, there are applications available for tracking a patient's medical records, particularly their blood glucose levels, as well as setting up reminders that can aid in improving diabetes control	Diabetes self-management is limited to only those patients who have the device and are technologically literate

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Objective of the paper	Methodology used	Result analysis	Advantages	Limitations
In this paper [16], usability evaluation of mHealth diabetes applications is performed for diabetic patients by utilizing a reformed heuristic evaluation method that includes (1) specialists of dual-domain (2) validated scenarios and user activity thorough assessments and ratings of severity factor	Heuristic evaluation method: The methodology involved: a. Expert evaluators: Experts were chosen based on their expertise with usability, their status as healthcare professionals, their knowledge of patient groups and their job requirements, and their knowledge of diabetes self-management b. User scenarios and tasks: The goal was to simulate how patients would use the system at a clinic or at home as part of a self-management approach. The panel was created which included physicians, registered nurses, and public health professionals c. Severity rating factors and scale: The heuristic evaluation (HE) methodology entails awarding a single severity score that is separated into frequency, impact, and persistence aspects	• There were 129 usability issues and 274 heuristic violations. Application views include Dashboard, Glucose Diary, Blood Pressure, and Medical Adherence View. Across these views, the number of usability issues ranges from 12 (low) to 34 (high) • Informaticists can use the modified HE to perform quick and resource-efficient heuristic processes. HE is employed in usability evaluation and is well suited to mHealth applications for chronic disease patients	• Dual-domain expertise brings some new and useful elements for evaluating usability • Dual-domain experts help improve user experience design • Dual-domain expertise can also assist in discovering patients' safety concerns that they may not be aware of	• Heuristics is complex • Highly skilled professionals are required for such evaluations
In this paper [17], the authors evaluated the usability of mHealth applications for health characteristics of public and health literate design methodology. The application cost was used to compare the health literacy aspects of diabetic apps (free or not) their languages, interfaces available, and user score	Expert-based usability evaluation methods: a. Diabetes-related keywords were typed into the Apple app store's search bar for iOS devices b. The information provided includes title, price, classification or category, rating related to age, total ratings in number given by application users, and star rating that range from 1 to 5 (with 5 being the best rating) c. Categories were created for three public health factors and four health literacy design methodologies or strategies. Types of diabetes, its continuum (diabetes behavior), and application emphasis were all categorized as public health factors. Type 1, Type 2, gestational diabetes, pre-diabetes, and others were several types of diabetes	• The paid applications were more useful in comparison to the free applications as they included more features • Paid apps used common everyday words. Paid apps also avoided the use of technical and medical terms that are not defined • Links were labeled more clearly in paid apps • Paid apps included a "back button." No other differences were there between paid and free apps related to organizing strategies	• The sample of diabetes-related applications coded was highly rated by the users and was appropriate for both children and adults • Resources are available to help improve the health literacy of the available mobile diabetes applications	• Diabetic applications which are paid were more likely to use common phrases used every day, and only premium or paid apps avoided using undefined technical and medical terminology. Paid applications displayed the content more clearly

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Objective of the paper	Methodology used	Result analysis	Advantages	Limitations
The authors of this [18] study conducted a systematic analysis of the diabetes applications which are available in iOS and Android and evaluated their functionality	Expert-based usability evaluation method: a. A search and screening technique for iOS and Android apps was developed with the help of information collected while using Apple and Google Play Store b. Categories "Health and Fitness" and "Medicine" were chosen for performing the search and screening strategy c. An expert-based usability assessment on the basis of a 10% sample of existing diabetes applications was performed as of April 2013 The chosen criteria were divided into main and sub-criteria, and experts used a Likert scale having 5 points to grade each sub-criterion. The mean of the sub-criteria was used to determine the key criteria ratings or scores	• In total, 656 applications were analyzed, of which 355 applications offered were only one function and 348 provided documentation function • On average, users gave it a 3.6-star rating. In the usability evaluation, 66 applications were evaluated • The "Comprehensibility" criterion was used to rate applications. The ability to read screen material aloud was available in 48 of the 66 applications	• Diabetes applications for age 50 and above were moderate to good in usability terms. The reviews concentrated on iOS and Android which are the most widely used operating systems	• The performance of applications having multifunctional capabilities was not satisfactory in terms of usability • This study did not take into account diabetes applications for Windows Phone or Blackberry • Paid applications were more organized
This paper [19] focuses on health information system assessment or evaluation methodologies that have developed from cognitive methods and usability engineering techniques	Heuristic evaluation and cognitive walkthrough method: usability testing and inspection are used Usability testing involves i. Exploratory tests carried out during the SDLC phase during preliminary design ii. Prototype testing carried out during requirement gathering iii. Validation checks to ensure that the software developed is suitable. Some inspection methods can be: • Heuristic assessment or evaluation—whether the user interface adheres to a collection of heuristics • Pluralistic walkthrough—a meeting in which researchers and users address usability issues • Cognitive walkthrough—stimulates the user's behavior and cognitive processes when performing tasks	Through the questionnaire, we were able to collect information such as the demographics, the users' age, and whether they use computers regularly A description of the task hierarchy is generated by cognitive task analysis. Video recording and screen capturing software, like Lotus Screen Cam, was used to capture the computer screens	• A variety of approaches to evaluate clinical information systems have also been developed and refined • Heuristic evaluation and cognitive walkthrough, the most popular evaluation methodologies, are used to assess healthcare systems • Advancements have been made for evaluating simulated or naturalistic events	• Some of the evaluation methods are time-consuming • It is challenging to integrate data acquired from different evaluation methodologies. Moreover, the potential relationship among the methods is not developed

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Objective of the paper	Methodology used	Result analysis	Advantages	Limitations
The authors of this study [20] evaluate the work that has been done in the field of user testing, with the aim of clarifying or specifying test procedures and identifying and improving resources to aid in the conduct of user tests. In this paper, user-based evaluation and Remote usability evaluation are performed	User-based evaluation and remote usability evaluation method: a. User-based evaluation is done involving the users to participate directly b. User performs tasks with the product and explores the product freely. Their behaviors are observed and recorded c. During the observation process, the time it takes to complete the assignment, the pace or rate at which it is done, and the types and number of errors are all captured and recorded d. Remote usability evaluation is performed in which the test participants are not present in the same location	• The study of the diaries takes into account the activities occurring in real-time environments. Participants record the activities • Computer screens are shared using video conferencing and sharing tools related to remote applications • The behaviors of the users are captured, collected, and then visualized as to which Web pages the people have explored	• It allows evaluators to interpret and visualize data • The events that are recorded can be transferred, i.e., exported to statistical tools for analysis • Since audio and video recording of user test sessions are done, it helps in indicating the area where the user faced problems • Both the user test and the empirical usability test are well documented	• Usability evaluations are costly • It is difficult to automate a process that eliminates the need for manual recording or logging • Tools for user test that includes data capture analysis of data and data representation are partially complete

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Objective of the paper	Methodology used	Result analysis	Advantages	Limitations
The study's [21] objective is to observe if an approach involving multi-method for collecting data and interpretation for patients' experiences with the mHealth applications related to self-management of Type 2 diabetes is feasible	Heuristic evaluation, cognitive walkthrough, and think-aloud methods: • Usability is assessed using heuristic evaluation and cognitive walkthrough which are the expert methodologies • Think-aloud method for assessing usability is used. Questionnaires and in-depth interviews are also used • The qualitative data is examined using Framework Analysis (FA). It assists in the study of descriptive, structured, and textual data sources, yielding reliable and qualitative results. There are five levels of FA 1. Familiarize the results with the details/data 2. Decide the framework or structure that is to be used 3. Create an index and use the structure to organize the results 4. Using a graph to display data 5. Mapping and interpreting the data	• Multiple kinds of data gathering methods result in a diverse set of issues related to usability and aid in the triangulation of data. Think-aloud usability testing was important for materializing the usability issues • The use of an in-depth interview and a questionnaire allows for data triangulation in the case of serious usability concerns • Data analysis using FA is a defined • UPT helped in an in-depth scheme classification and in the determination of severity rating score	• Methods of data gathering resulted in a thorough and full set of problems or issues related to usability, as well as the ability to triangulate (validate) the data • The structured data analysis helps in data validation to determine the most severe problems for the users • FA provides a feasible way to solve the usability problems from huge qualitative data • UPT aids to assess severity score or for the usability issue	• The study uses a randomized sample of diabetic patients drawn from a large and convenient sample. The frame of convenience sampling related to a big study makes it difficult to apply the observations to diabetic patients

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Objective of the paper	Methodology used	Result analysis	Advantages	Limitations
Authors in this paper [22], complete the evidence-based approach for assessing the mHealth system. The study serves as a model for well-organized usability techniques	Heuristic evaluation method: • The research used various methods recommended in ISO standards for assessing effectiveness, satisfaction, and efficiency including the SUS (System Usability Scale) instrument • Task completion success is used to determine effectiveness, followed by a count of the number of errors made during communication • The amount of effort and resources used by the users are also considered when determining performance • Satisfaction can be measured by the SUS instrument • The reliability, sensitivity, and validity of SUS are assessed • The SUS score is a number that varies from 0 to 100. A score of 70 or higher is considered suitable or fine, while a score of 35 or higher indicates a high usability degree level or an excellent score. A score of 50 or lower implies usability that is unacceptable	• The tasks related to export and fix values had the highest number of errors and the most amount of time spent on them • The average SUS satisfaction score of the system was 80.5, which signifies decent usability • According to the data, males finished the task more successfully and the young participants had high-performance scores • Microsoft Excel Spreadsheet was used. SPSS version 22 constructed and calculated descriptive statistics on effectiveness, efficiency, and satisfaction	• The analysis yielded a more comprehensive quantitative evaluation of usability • The findings provided information to the developers about the areas in which patients have problems and in which activities can be made perfect to suit or adjust users • The research is being used as an example for evaluating mHealth systems and wants to provide a benchmark to have repeatable and comparable outcomes	• This research used a small sample of users from a specific diabetes group, making it impossible to generalize the results to the general population • Since the participants are selected randomly, there is a fair chance of including the participants who are less or not literate
The authors of this paper [23], assess and compare the usability of three mobile applications for diabetes self-care	Think-aloud method: In this, usability testing is adopted for evaluating the diabetes application's usability. A total of 30 people with Type 2 diabetes (15 men and 15 women) took part in the usability evaluation. After completing task scenarios collection, participants tested the program with the aid of the scale known as System Usability Scale (SUS). Participants followed the think-aloud protocol while operating the applications	• The mean SUS of Application 3 was higher than the scores of Applications 1 and 2 • The high SUS and screenshots found throughout the think-aloud protocol process help in developing diabetes self-care applications	• The SUS score of Application 3 was higher than the scores of Application 1 and Application 2 • The advantages identified during the think-aloud protocol aid in the design of diabetes self-care	• Designers should take into account the concerns raised by elderly participants • The findings could be used to boost the usability of diabetes self-care apps

3 Objectives of the Study

The objectives of this paper are as follows:

- Identification of usability attributes apart from traditional Nielson [11] usability attributes, which can contribute to better usability assessment of mHealth applications.
- Comparing various usability evaluation methodologies adopted by researchers as shown in Table 1.
- Identifying the design flaws of mHealth applications and assisting them with guidelines in enhancing design solutions.

4 Usability Attributes

For assessing the mHealth applications, we commonly use the Nielson Model [11]. The attributes are discussed as follows.

- **Learnability:** When a user encounters a design for the first time, their learning ability can be characterized as how quickly and competently they can handle the basic activities. It also involves how efficiently the user can keep in mind the knowledge while usage.
- **Efficiency:** Efficiency measures how quickly and precisely the user can finish the task after being familiar with the design.
- **Memorability:** Memorability refers to how quickly users may regain expertise after being away from the design for a period of time.
- **Errors:** This refers to the frequency of errors produced, the seriousness or severity of the faults, and the methods for recovering.
- **Satisfaction:** The level of satisfaction with mHealth applications is measured by the satisfaction attribute. It refers to the comfort, likability, and pleasure of the user.

Apart from Nielson's attributes, in this work, we have identified some more attributes which contribute greatly to the significant usability evaluation of mHealth applications. These attributes are mentioned below:

- **Aesthetic design:** Aesthetic refers to the addition of simple and attractive features to the mHealth applications. The mHealth application should be designed so that it has pleasing qualities as well as simple to be used by all groups of users. The functionality of the mHealth applications can be enhanced by the inclusion of simple layouts which will fascinate the user.
- **Navigation**: Navigation of the different features of the mHealth applications should be very easy; otherwise, the users will find it difficult to evaluate the mHealth applications. If navigation is proper, it ensures that the user can navigate the mHealth applications without any problem.

- **Readability**: The content of the mHealth applications must be readable. Readability involves legibility and understandability. The mHealth applications should be legible in terms of color combinations, word style (italic, bold, etc.), font size, and typeface.
- **Cognitive Load:** The number of working memory resources (such as thinking, reasoning, and remembering) necessary to operate mHealth apps is referred to as cognitive load. The cognitive load of the mHealth applications should be reduced. Some ways in which cognitive load can be minimized are by removing the non-essential contents, breaking the content into smaller segments, presenting information both visually and verbally, etc.
- **Provision for Physically challenged users:** A group of users accessing mHealth applications can have certain physical disabilities such as hearing disability, motor disabilities, and vision problems. The user interface of the application should be able to manage these types of user groups as well.

5 Results and Analysis

For the literature review, the screening of different papers related to diabetes mHealth applications was carried out and eligible papers of this study were selected. Figure 1 depicts the flow diagram for the selection process of the included studies. Objectives, methodology used, result analysis, advantages, and limitations of 11 papers were discussed in this study. Figure 2 shows the graph of the papers reviewed in this study based on the years of their publications. By the year of publication, 9.1% of the studies ($n = 1$) were published between 2001 and 2005; 9.1% of studies ($n = 1$) between the year 2006–2010; 18.2% of the studies ($n = 2$) between the year 2011–2015; and 63.6% of the studies ($n = 7$) between the year 2016 and 2020. Through this study, a few more attributes are identified that include aesthetic design, navigation, readability, cognitive load, and provision for physically challenged users.

6 Conclusion and Future Work

For significant evaluation of usability, different attributes have been suggested by researchers which helps greatly for better performance and efficiency. Usability has been disintegrated into sub-attributes which are the hypothetical concepts for defining the success of the system. The involvement of the user also plays an important role to determine the usability of software applications once it has been made. A comparison study has been incorporated in this work which identifies the various attributes that play a significant role in evaluating mHealth applications and also describes the usability evaluation models used along with their advantages and limitations. In this paper, different UEMs were presented which helped in the identification of the most

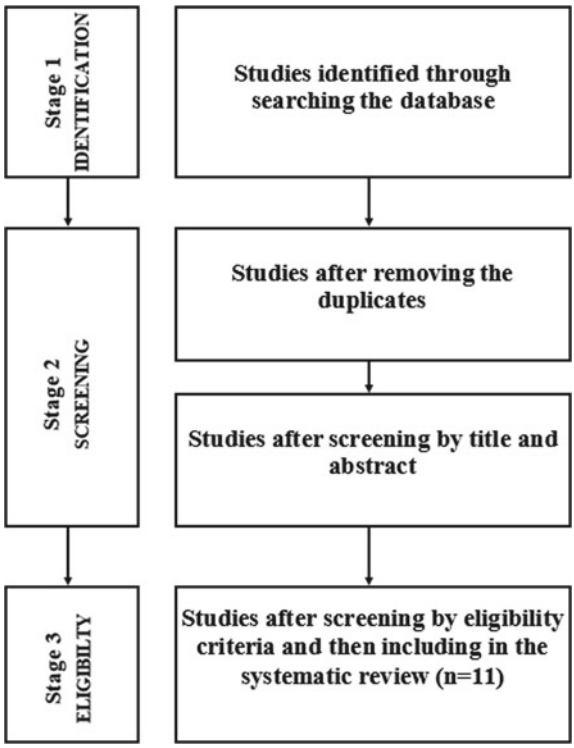

Fig. 1 Flow diagram for the selection process of included studies

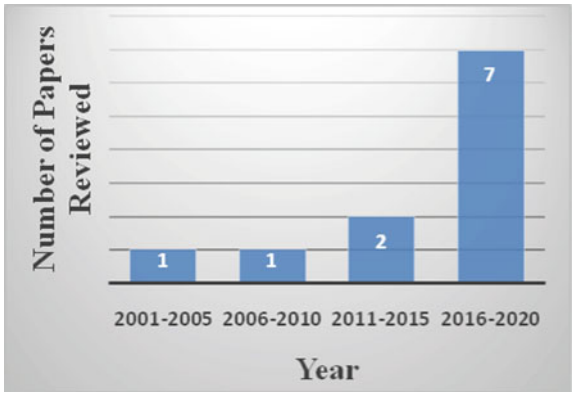

Fig. 2 Papers reviewed based on the years

important features relevant to the most suitable method for evaluating mHealth applications. Therefore, this paper will provide a pathway for the evaluators in choosing the most suitable UEM that may assist in evaluating a particular situation. This paper will be advantageous for the researchers and the students who are contributing in the software engineering field.

Future research to assure patients' adapting the mHealth applications should include the training needs of the patients, the problems they face while using the mHealth applications, and expedite its use for the long term. Inputs from the caregivers should be considered as they play a vital role in helping the patients to involve themselves in positive health behaviors while performing self-management.

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