Crowdsourcing Users' Comments for Clinical and Operational Features Analysis of Diabetes Mobile Apps

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Abstract

Today there exists a plethora of mobile apps focused on diabetes self-management. To understand the rate of inclusion and influences of these numerous diabetes mobile apps (DMAS), we crowdsourced and analyzed negative users' comments and the design features of numerous apps, underpinned by fit viability and grounded theory as the theoretical analysis lens. Thus, by concentrating our efforts on apps written in English collected from google play and apple app store, we identified and classified DMAS as a health monitoring app (HMAS) and information repository apps (IRAS), and statistically determined the effects of different diabetes self-management indicators on their functionalities. Our results affirm that these solutions have limited functionalities to facilitate self-management of diabetes due to poor design which hinders intelligent decision support, as well as limits inclusion and performance of wellness support features. Also, many of these apps are operationally inefficient.

1. Introduction

This era of Internet connectivity has transformed our lifestyles to be more online and reliant on mobile apps to provide us with information and support concerning wellness and self-management of chronic conditions [1]. Thus, it should be of no surprise that over 1 million mobile health apps [2] have been downloaded over 3.7 billion times [3] because most of these are advertised as vital tools for managing chronic conditions such as diabetes. Unfortunately, the ubiquitous nature of these apps has not translated into quality products [4], hence, there exists a key need to understand the challenges of such apps and identify critical enablers to facilitate better designs. The extant literature shows that many mobile app developers have targeted patients with diabetes primarily because of the potency of proper self-management in maintaining appropriate blood sugar levels [5]. This, however, has given rise to largely poor quality diabetic mobile apps (DMAS), which though may have good ratings from the Mobile App Rating Scale – MARS [6] are insufficient for managing wellness or supporting self-management as noted by personal experiences of users. Given this conundrum; that many DMAS are not effective for diabetes management [7-8], we address this by answering the following key research questions:

- **Q1**: How can we identify the DMAS that are useful for efficient diabetes management? Evidence from research already points to the multiplicity of inefficient DMAS that are not able to control the glycaemic level of patients with diabetes [7-8].
- **Q2**: What is the best way to classify DMAS to reflect their functionality? This will make it easier to distinguish between those designed to provide health monitoring from those providing general diabetes management information [9].
- **Q3**: What is the best way to source this information to obtain users' experience of the DMAS performance to enable the extraction of the key problems from the practical experience of users? It can be shown from the literature that numerous studies on DMAS have limited consideration of users' experience [1,10].
- **Q4**: How efficient are the features used in DMAS development? The need to understand via statistical analysis the inclusion rates of the various design feature will provide information about the advances needed in DMAS.

To answer these questions and provide a suitably rich theoretical lens of analysis, the fit-viability model [11] was adopted by matching the clinical and operational features of DMAS against different quality benchmarks to measure fit while viability is determined by confirming developers claimed performances against users' experience. We decided to compile DMAS, determine their features while crowdsourcing the comments of users with poor experience (rating: 1 – 3) because of the limited

URI: https://hdl.handle.net/10125/71044
978-0-9981331-4-0

confidence in developers' comments [12]. Emphatically, there is a higher likelihood of extracting useful information about the apps' features and performance from genuinely disappointed users since some of the positive feedbacks are not genuine [13]. It is also important to develop some hypotheses based on the apps classifications to establish how developers are utilizing these essential features in developed DMAS following some statistical analysis, hence, buttressing the fit-viability model.

This study, therefore, aims to utilize the available information from developers' and users' comments to characterize DMAS to provide suggestions for a better way of classifying DMAS based on some key functionalities. Following the analysis of the performance flaws of the apps from users with negative experiences and comparing them with developers' narratives, we will establish a descriptive summary of the characteristics of an efficient diabetes app. The characteristics that have been efficiently utilized by developers will also be extracted and the core problems of dysfunctional apps will be exposed, hence, giving future developers a vital tool for designing efficient health management tools. We will therefore rely on the fit and viability model, grounded theory, and statistical analysis of variance to establish the core challenges of DMAS from statistical and thematic analysis viewpoints.

1.1 Brief Overview of Diabetes

The growth of diabetes, a substantial noncommunicable, chronic disease, is a major source of concern for policymakers because of the alarming 4.2 million deaths it caused in 2019 and over USD 760 billion economic burdens to the world [14]. Unfortunately, over 500 million people suffer from diabetes type 2 and this is rapidly increasing in developed countries [15] due to sedentary life, obesity, and other genetics and environmental conditions that are less well understood.

Given the peculiar nature of this condition, patients with diabetes can only maintain wellness via long-term care plans that lower the blood glucose level following exercises, diet modification, and regular medication [16]. In addition, they typically have a dependence on glucophage, sulfonylureas, meglitinides, thiazolidinediones, DPP-4 inhibitors, and GLP-1 receptor agonists-based medications for managing the condition.

Many patients with diabetes struggle with the self-management of the disease despite the continuous reliance on different mobile apps due to the financial consequences of the lifestyle changes associated with diet plans and regimented exercising [17]. Despite the use of these apps for managing blood sugar, carb intake, dietary and nutrition information extraction, and appointment scheduling [1,18,19], several patients with diabetes also suffer from poor understanding of the disease.

1.2 Fit and viability model

From theory, it is possible to try to unpack the potential poor sustained use in terms of poor fit. Hence, we proffer the fit-viability model as a suitable analysis lens which combines the dimensions of fit viability and task technology fit. Tjan [28] proposed fit viability dimensions for evaluating Internet initiative projects. Liang and Wei [11], incorporated these two dimensions with Task Technology Fit (TTF) theory, to develop the fit-viability model to study m-commerce applications. In this framework, viability measured the readiness for the technology adoption and implementation, and fit measured capabilities of the systems to optimally perform the required tasks. Muhammad and Wickramasinghe [29] have since further adapted this framework to apply it to the assessment of health technology solutions.

For the current study, it is important to identify that a good fit between task characteristics and system features is essential for optimal blood glucose level maintenance while noting the external impacts such as political, social, economic, environmental, and technical factors that can impede the adoption and implementation of the solution [30,31]. Despite all the factors, which constitute the viability of a system, in the current context, we include the technical abilities of DMAS to support the self-management of diabetes through the design features. Thus, providing the clinical and operational support framework that will enable patients with diabetes to have seamless operations in their daily management of the disease.

1.3 Grounded theory

To analyze the negative reviewers comments and understand the challenges of DMAS beyond the design features, Grounded Theory, which focuses on the thematic investigation to develop new concepts for coding the ideas present in qualitative information is used [45]. This technique helps to understand the main ideas in qualitative data to give a guide for establishing the perception of users with negative experiences in a generalizable manner. Thus, repeated reviewing that culminated in continually reading the comments to establish the subjects, and notions behind every reviewer's comment was necessary for capturing the evidence of the poor performance of DMAS. By extracting and tagging comments with these codes, it was possible to group them and re-reviewed all information into themes and concepts that are worthy of describing theories governing the data for DMAS challenges classification. Following a literature search, the themes identified were established to be among the challenges reported by previous researchers [7,8, 34,42, 43, 44]. It is important to state that grounded theory has been used for numerous studies relating to diabetes such as the exploration of the sources of information for newly diagnosed patients with diabetes [46]. The psychological narratives of diabetes self-management and the efficacy of different practices needed for the successful implementation have also been studied with grounded theory [47] while treatment selection for diabetes type 2 was determined by other researchers [48]. Giving the importance of this technique and its previous use for assisting an understanding around the barriers to effective utilization and adoption of mobile apps for mental health [49] to evaluate the effectiveness of different treatment options, we affirm that it will provide a viable option for understanding the challenges of DMAS.

1.4 Hypotheses development

There is no doubt that DMAS are freely available for users though it may be with limited functions as against paid ones. But the poor functionality of these apps [4] is a cause for concern as many of the signature features claimed by the developers are not working properly [8] thus, resulting in users' frustrations. There is also limited evidence to support the effective utilization of DMAS in self-management of diabetes despite the widespread utilization of many apps [42] while deprived functionality [41], poor user interface and graphical outputs, and poor analytics [42,44] are resulting in poor estimation of the blood sugar levels [43]. These challenges that can be traced back to poor design [8], inadequate diabetes educational materials and poor doctor-patient communication [43] are impairing the adoption of these apps [41]. In the light of this and the limited information in the literature to guide developers and users on the fundamental qualities of an effective self-management DMAS, we decided to test the following null hypotheses:

- **H1**: Wellness support information of diabetes mobile apps are not positively associated with diabetes self-management.
- **H2**: Intelligent decision support functions of diabetes mobile apps are not positively correlated with diabetes self-management.
- **H3**: The performance of diabetes mobile apps is poorly correlated with their operability, compatibility, and flexibility.
- **H4**: There is no strong relationship between diabetes health monitoring apps and patient's information management.
- **H5**: The information repository of diabetes mobile apps is not strongly correlated with contemporary diabetes self-management educational materials.

2. Methods

2.1 Data acquisition and characterization

A search was performed with the following keywords "diabetes apps", "diabetes apps for android", and "paid diabetes apps" in google, google play, and apple app store. An app is selected if it is written in English, used for diabetes self-management, and has both positive and negative users' reviews. Although previous studies relied on the top-ranked apps based on the high user rating [1], we did not follow this strategy because many positive comments from users are not reliable [12]. After eliminating duplicated apps, the obtained 253 apps were further classified to determine those without any significant design features relevant to diabetes self-management despite being described as such. The selected apps were identified with the app's name, developer name, price, star-rating, type of operating system (android and IOS), and other features, which include clinical and operations following the framework shown in Figure 1.

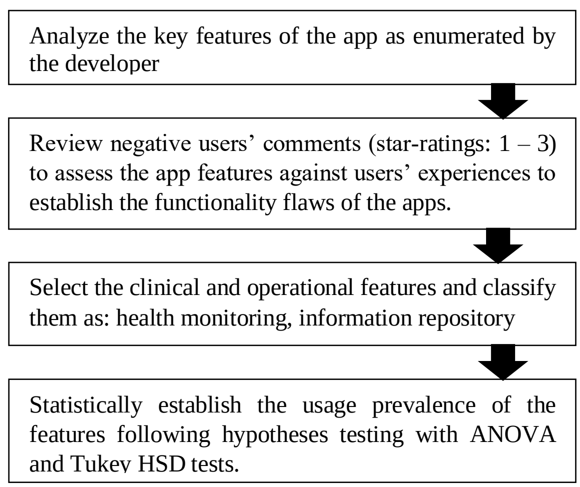

Figure 1: Diabetes mobile apps classification technique for health monitoring and information repository grouping following the clinical and operational features classification

The apps that were classified as health monitoring were identified with specific clinical, operational, and data management characteristics that can help the users in self-management of diabetes progression following data measured automatically or fed to the apps. The core app features considered for the classification and some literature references that informed their use is summarized in Table 1.

Table 1:Taxonomy for diabetes mobile apps (DMAS) classification showing the core characteristics identified via the developer's information and crowdsourcing of negative user's review comments

	Classifications and subgroups	Abbrev.	Ref
1	**Health monitoring apps (HMAS)**		
	clinical & operational support features		
a.	*Wellness support information (WSI)*		
	Nutrition, exercise, and health tips	NEH	[22]
	Meditation, thoughts, and behavior management	MBM	[21]
	Social support	SNE	[32]
b.	*Intelligent clinical decision supports (ICDS)*		
	Health and medication analysis	HMA	[1]
	Lab report inclusion and prescription management	LPM	
	Carb intake and sugar level analysis	CSA	[17]
	Scheduling and reminders	SRE	[20]
	Doctor's report and appointments	DRA	[18]
c.	*Operability, compatibility, and flexibility (OCF)*		
	Automatic synchronization	ASY	
	Bluetooth connectivity	BCD	
	Smart assistance	SAS	
	Location monitoring	LMO	
d.	*Efficient data management (EDM)*		
	Data backup and export	DBE	[33]
	Report modification (ability to edit reports)	RMO	
2	**Information repository apps (IRAS)**		
	Diet information	DIF	[34]
	Exercise information	EXI	
	diabetes overview	DMGT	[34]
	Support for behavior change	SBC	

2.2 Statistical analysis

Following the estimation of the baseline summary statistics of the various diabetes mobile apps (health monitoring and information repository), a one-factor Analysis of Variance (ANOVA) and Tukey HSD were used to establish the significance of the signature features that constituted the core characteristics at a significant level of $P \leq 0.01$ while using Shapiro-Wilk test for the univariate analysis of the various characteristics. We used ANOVA to test the impact of the various attributes of the clinical and operational features on the wellness support information, intelligent decision support, operability, compatibility and flexibility, and efficient data management of DMAS. The same strategy was also used to determine how information repository apps are influenced by the constituent features. To understand the functional difference between the proportion of the total apps and the total subgroups, a chi-squared test was used.

3. Results and Discussion

3.1 Baseline characteristics of identified apps

Figure 2 shows the summary of the classification of DMAS following the broad taxonomy of health monitoring and information repository. A total of 125 of the 253 searched apps have nothing to do with diabetes management whereas 37 are information repository apps and 91are health monitoring apps.

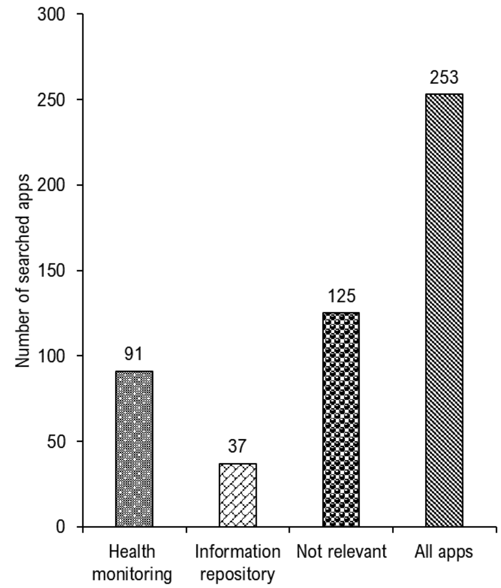

Figure 2: Summary of the result of the search based on the broad classification of diabetes mobile apps (DMAS) as health monitoring and information repository apps.

According to Table 2, between 11% - 33% (P<0.001) of the DMAS have wellness support information characteristics while 5% - 55% (P <0.001) have "*intelligent clinical decision supports*" attributes. The rest of the attributes are "*operability, compatibility & flexibility*": 1% - 14% (P<0.001), "*efficient data management*": 3% - 21% (P<0.001) and information repository: 8% - 23% (P<0.001). There is no functional composition difference between the proportion of the DMAS's characteristics computed as proportion of total apps analyzed (PTAA) and proportion of app's sub group (PASG) following the chi-squared analysis detailed for the "*health monitoring apps*" (χ^2 =182, P-value = 0.234) and the "*information repository apps*" (χ^2 =12, P-value = 0.2133).

3.2 Prevalence of diabetes mobile apps features

Since the DMAS features are vital for user's satisfaction via efficient self-management of diabetes, it is necessary to know the extent of prevalence of the features among the studied apps thus, providing useful information for future developers. The Shapiro-Wilk test also showed that the features are not normally distributed (P-value <0.001) because of the difference in the inclusion of the features in the various studied apps. This has considerable ramifications for the quality of most of the apps as patients with diabetes cannot be adequately supported to manage their conditions effectively. To substantiate this, the summary statistics of the features and the hypotheses as determined with the ANOVA and Tukey HSD are shown in Table 3.

Table 2: Metadata analysis of the diabetes mobile apps (DMAS) characteristics of - health monitoring apps and information repository apps, PASG: the proportion of app's subgroup, PTAA: the proportion of total apps analyzed, * : estimated with Shapiro-Wilk test

	Classifications and subgroups	PTAA	PASG	P-value*
1	**Health monitoring apps(n=91)**			
a	*Wellness support information (WSI)*			
	Nutrition, exercise, and health tips, NEH, n=42	33%	46%	<0.001
	MBM, n=14	11%	15%	<0.001
	SNE, n=21	16%	23%	<0.001
b	*Intelligent clinical decision supports (ICDS)*			
	HMA, n=70	55%	77%	<0.001
	LPM, n=6	5%	7%	<0.001
	CSA, n=82	64%	90%	<0.001
	SRE, n=34	27%	37%	<0.001
	DRA, n=28	22%	31%	<0.001
c.	*Operability, compatibility, and flexibility (OCF)*			
	ASY, n=18	14%	20%	<0.001
	BCD, n=17	13%	19%	<0.001
	SAS, n=3	2%	3%	<0.001
	LMO, n=1	1%	1%	<0.001
d.	*Efficient data management (EDM)*			
	DBE, n= 27	21%	30%	<0.001
	RMO, n=4	3%	4%	<0.001
2	**Information repository apps(n=37)**			
	DIF, n=17	13%	46%	<0.001
	EXI, n=11	9%	30%	<0.001
	DMGT, n=29	23%	78%	<0.001
	SBC, n=10	8%	27%	<0.001

3.3 Answering research questions and hypotheses testing

To answer Q1, we identified the features of DMAS that are important for self-management of diabetes and classified the core attributes using the clinical and operational functions. Q2 was answered by using "*wellness support information*", "*intelligent clinical decision supports*", "*operability, compatibility & flexibility*" and "*efficient data management*" attributes to classify the features for quick identification of the key functionalities of self-management activities [40]. Thus, giving patients with diabetes the opportunity to effectively choose efficient apps for diabetes self-management and proffers support for enhanced design and development of usable DMAS [7,40].

By relying on the experience of unhappy users, valuable comments were obtained to validate developers claimed performances, hence helping to answer Q3. This makes it possible to know the true state of the clinical and operational features, thus, highlighting the important design and development flaws, which are common with many of the apps [2,37].

Table 3: Summary of P-value, adjusted P-value (P-adj), F-stat, ANOVA, Tukey HSD test, significant (SF), and non-significant (NS) parameters for the hypotheses(H0)

H0	F-stat	P-value	Tukey HSD Groups	Tukey HSD P-adj	Remark
H1	12.8	<0.001	NEH-MBM	<0.001	SF
			SNE-MBM	0.447	NS
			SNE-NEH	<0.001	SF
H2	76.1	<0.001	DRA-CSA	<0.001	SF
			HMA-CSA	0.127	NS
			LPM-CSA	<0.001	SF
			SRE-CSA	<0.001	SF
			HMA-DRA	<0.001	SF
			LPM-DRA	<0.001	SF
			SRE-DRA	0.762	NS
			LPM-HMA	<0.001	SF
			SRE-HMA	<0.001	SF
			SRE-LPM	<0.001	SF
H3	10.1	<0.001	BCD-ASY	0.995	NS
			LMO-ASY	<0.001	SF
			SAS-ASY	0.001	SF
			LMO-BCD	<0.001	SF
			SAS-BCD	0.003	SF
			SAS-LMO	0.959	NS
H4	23.3	<0.001	RMO-DBE	<0.001	SF
H5	10.4	<0.001	DMGT-DIF	0.011	SF
			EXI-DIF	0.400	NS
			SBC-DIF	0.263	NS
			EXI-DMGT	<0.001	SF
			SBC-DMGT	<0.001	SF
			SBC-EXI	0.994	NS

Since the best way to determine the effectiveness of DMAS feature utilization will involve statistical analysis, we were able to answer Q4 using the frequency of features utilization and statistical analysis that hinged on ANOVA. Therefore, providing vital information for designing new DMAS since developers can count on them for combining attributes that will improve the adoption and usability of DMAS [37,40].

Following the P-values of <0.001 and F-stat of 12.8 (Table 3), *H1 is accepted*. This implies that the limited information in the "*health monitoring apps*" are not sufficient for self-management of diabetes. This sentiment is shared by some researchers who affirmed that limited wellness information in most DMAS hampered blood glucose control [35,36,39]. This limited wellness information capability is evident in the combination of "*nutrition, exercise & health tips*" and the "*social support*" features and "*nutrition,* *exercise & health tips"* and "*Meditation, thoughts, and behavior management*" features in most of the studied DMAS. Unfortunately, most of the apps cannot be used as a medical device [35] for "*intelligent decision support*" since there is a statistically significant difference (ANOVA test, P <0.001), thus, making it *possible to accept H2*. Although most of the "*health monitoring apps*" have "*health & medication analysis*" and "*carb intake & sugar level analysis*" features that enable the capturing and managing of the blood sugar levels, due to the poor configuration of these features, the effectiveness of some of the apps in recording and managing the blood sugar levels were compromised. When some of them are incorporated into the care plans of the patients with diabetes, the flawed designs will impact the management process and could result in serious health complications in extreme cases due to poor blood glucose management [39].

We accepted the H3 (P-value <0.001 and F-stat = 10.05) *and H4* (P-value <0.001, F-stat = 23.31). Even though 41% of the "*health monitoring apps*" have no "*scheduling & reminders*", and "*doctor's report & appointments*" features, only 12% of them have these features synchronously included in the apps, hence, making it difficult for users to take full advantage of automatic scheduling of doctors' appointments and reminders. The remaining functional features that enhance "*operability, compatibility, and flexibility*" of DMAS were greatly impaired due to the poor design and development [2,7]. Data security and management are also poor as most of the apps lacked functionalities for managing the acquired blood glucose measurements in a database whereas the possibilities of a secured data transfer and storage are lacking. Again, with 20% and 19% of the "*health monitoring apps*" having "*automatic synchronization*" and "*Bluetooth connectivity*" features respectively, it is expected that the majority of the users will benefit from the seamless operations of the Bluetooth and automatic synchronization to facilitate the measuring and transferring of various information. Nonetheless, the myriads of botched connections, failed updates, server unavailability, and the numerous intermittent crashes on start-ups of the apps after updates left most of the users with bad memories.

H5 (P-value <0.001, F-stat = 10.43) *is also accepted* as the knowledgebase of most of the "*information repository apps*" are not current. This poor acquisition and use of contemporary research information impaired the effective utilization of the apps for diabetes self-management. Despite the "*information repository apps*" having "*exercise information*" and "*diet information*" features as prominent attributes, the reliance on information that are not scientifically proven or superseded scientific information invalidated the usefulness of these features. Thus, robbing the users of some valuable insights for self-management and then questioning the ubiquitous release of unregulated DMAS [36] to the public. This unfortunate scenario combined with the limited social support to patients with diabetes can complicate their wellness [20-23]. As a result, some of them have been prone to early unplanned readmission, putting more pressure on the health system. Unfortunately, those with other comorbidities have been identified to be at a higher risk of this frequent hospitalization especially if they suffer from dementia, depression, chronic heart conditions [24], psoriasis, psoriatic arthritis [25], ankle fracture [26], and asthma [27].

3.4 Crowdsourced challenges of diabetes mobile app

The major challenges users of the studied DMAS faced as determined from the negative reviews of 780 users' comments are summarized into six groups that include health monitoring problems (HMP), operational issues (OPR), information quality (INQ), data security, and safety (DSS), diet and exercise challenges (DEX) and others (OTH). This information was obtained through thematic analysis by using numerous keywords that mapped the statements into their various classes following the grounded theory per Figure 3.

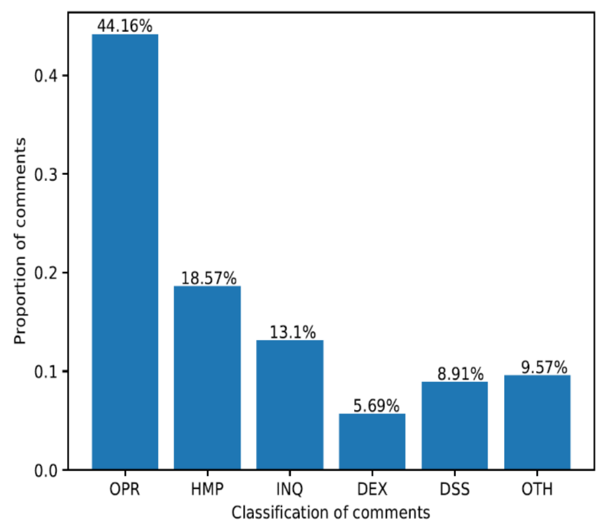

Figure 3: Categorization of diabetes mobile apps problems according to negative reviewers' comments.

There are 44.16% comments that related to "*operational issues*", some of these included crowded user interfaces that are difficult to navigate, poor synchronization and Bluetooth connectivity of DMAS with glucose probes and servers, frequent crashing and freezing after updating, malfunctioning of features such as calendar and compatibility problems with other auxiliary devices. The predominant "*health monitoring problems*", which accounted for 18.57% of the comments include poor estimation of blood glucose levels, inaccurate carb and calories computation, difficulty adjusting medication dosage in apps, problems with insulin management, poor meter readings, poor and inability to track weight, blood pressure, and heart rates, and narrow input range of glucose level that cannot be overridden. There are many "*information quality problems*" with the apps, and they accounted for 13.1% of the comments. Some of the "*health monitoring problems*" complaints include low quality of printed reports, need for offline information retrieval, poor data transfer structure, nonexistence or poor user manuals, inability to switch between metric and imperial units of measurements. With "*data security and safety*" comments comprising of 8.91% of the users' views, the major concerns are the inability to track medication history, problem logging in diet information to facilitate carb computation, inability to edit inputs to correct errors, privacy intuition, poor data transfer protection, limited data storage and lack of long-term data storage. Complaints aligned to "*diet and exercise challenges*" are 5.69% and include outdated diabetes information, the inclusion of unsubstantiated diabetes management information, limited food choices and database, inability to log food not included in the database, and lack of diet plans. Other comments (OTH) that dominated the discussion are 9.57% and centered around false developers declared apps features, high cost of subscriptions, too many advertisements in apps, poor customer service, and the poor pace of developing new features to match operating systems changes.

4. Implications for theory and practice

Most of the mobile apps are "*health monitoring apps*" and accounted for 72.8% whereas 29.2% are designed as "*information repository apps*". The most predominant characteristics of the "*health monitoring apps*" are "*intelligent clinical decision supports*" feature, which has "*Health and medication analysis*" and "*carb intake and sugar level analysis*" design characteristics respectively present in 77% and 90% of them. Only 7% of the features are "*Lab report inclusion and prescription management*" attributes whereas approximately 1 in 3 has "*scheduling and reminders*" and "*doctor's report and appointments*". There is relatively less representation of the "*Wellness support information*" features ("*nutrition, exercise, and health tips*", "*Meditation, thoughts, and behavior management*", "*social support*") in most of the apps than the most represented features of the "*intelligent clinical decision supports*" ("*health and medication analysis*" and "*carb intake and sugar level analysis*") while "*operability, compatibility, and flexibility*" and "*efficient data management*" design features are only present in 1% - 30% of the "*health monitoring apps*". This scarcity of support information can impact the users who may not be able to develop enough behavioral changes and glucose management capabilities [34] expected for an efficient self-management of diabetes. To this end, patients with diabetes may have to rely on apps that have clinical certifications to get the expected benefits of using DMAS [37].

With approximately 1 in every 2 users comments directed to the poor operational efficiency of the apps, the impact of poor operability, compatibility, and flexibility on the DMAS performance efficiency can be further substantiated. Thus, making it imperative that thorough testing will be carried out before the release of these apps to forestall the consistent crashing, crashing, and freezing on start-up, crashing after updates, and poor computational accuracy of HbA1c levels. Unfortunately, the poor wellness information coupled with the dismal analytics of most DMAS have contributed to the minimal influence users have on their blood glucose level [8].

The inadequate inclusion of effective data management features calls to question the DMAS' ability to manage data securely especially during seamless operations that warrant synchronization, Bluetooth, and WIFI connectivity. Unfortunately, this trend is not new seeing that previous studies have associated some mobile apps developers with little to no consideration of data security and privacy concerns in designs [37,38]. Although only 1 in 11 users commented on data security concerns in the crowdsourced messages, the potency of data security and safety in mobile apps design cannot be overemphasized as one of the cardinal requirements for apps development [37]. Similarly, the poor assemblage of information in some of the apps especially "*information repository apps*" is another course for concern, because of the challenges it poses to effective self-management of diabetes. This can be leeway to exacerbation of the fragile health conditions of patients with diabetes who may unknowingly be trading their wellness for unwholesome practices, seeing that many of them cannot effectively manage HbA1c levels with the DMAS [39].

From the perspective of theory, the analysis of comments using Grounded Theory, to date has indicated the importance to take a socio-technical perspective with respect to the design and development and this in turn should ensure better outcomes for patients with diabetes. While task technology fit theory identifies the criticality of ensuring the apps are designed fit for purpose to support the required tasks the socio-technical aspects ensure the apps are user friendly and will be adopted readily. This extension to task technology fit, we believe is important and will be explored further in future work. In addition, our findings highlight that the need for hyper-personalization is another aspect that needs to be included and hence, it would behoove us to develop extensions to task technology fit theory in this regard as well. We expect that by combining these aspects with the existing task technology fit lens it will be possible to develop an appropriate rubric to assist the suitable design of such apps moving forward.

Following the results obtained, patients with diabetes interested in using DMAS for self-management must consider:

- Looking for the key features of health monitoring apps to ensure that the basic functionalities such as "*nutrition, exercise, and health tips*", "*health and medication analysis*", "*carb intake and sugar level analysis*", "*data backup and export*" will aid self-management of diabetes to monitor the HbA1c level if available.
- It may be necessary to ensure that the app is certified by relevant authorities as a medical device to guarantee that the key features are operating within the stipulated standards for obtaining credible blood sugar measurements.
- There is a need for patients with diabetes to collaborate with their doctors in choosing the apps that will be most suitable for their conditions as this will facilitate a good transition between self-management practices and clinical care.
- It may be a good idea to trial different apps before zeroing in on one because fantastic users' reviews may not culminate in the efficient performance of any app.

5. Limitations

This study is subject to the following limitations:

- The DMAS features were not analysed independently to establish the claims of the developers, but the crowdsourced users' negative comments helped to validate the claims following their various commentaries.
- We were unable to download the apps to establish the functionalities per the designers' claims notwithstanding, it can be noted that the flaws of these apps may not be identified within the limited use cases during a trial. This warranted the reliance on the numerous views of users who at different instances over the period of use were able to figure out numerous flaws.

6. Conclusions

This study analyzed diabetes mobile apps for health monitoring features and information repository attributes by searching the internet to identify those written in English that have characteristics consistent with the above search criteria. We identified 128 DMAS that were classified as health monitoring apps if they have clinical, operational features that facilitated self-management of diabetes following automatic or manually fed blood glucose levels or information repository app if they provided basic diabetes management information.

After classifying the apps, using statistical analysis, and crowdsourcing negative users' comments, we affirmed that they have limited functionalities to facilitate self-management of diabetes due to the poor designs that negate intelligent decision support. These apps are not operationally efficient as they cannot synchronize effectively with many auxiliary devices and most of them lacked current information, thus, making their capability to deliver effective diabetes self-management record doubtfulness.

As noted in the fit-viability model both elements of task-fit and viability are essential to ensure high, sustained uptake and usefulness of a solution. Hence our findings have implications for practice for DMAS developers and designers as well as patients with diabetes and their clinical care team. From the perspective of theory, our study is one of the first to apply fit-viability to the assessment of diabetes mobile solutions and suggests that this theory should be incorporated to assist in assessments of all mobile apps designed and developed for healthcare contexts to enable a rapid and accurate assessment of their usefulness and likely benefit.

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