ORIGINAL RESEARCH

A Mobile Application to Improve Diabetes Self-Management Using Rapid Prototyping: Iterative Co-Design Approach in Asian Settings

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Background: Diabetes is a global public health issue, causing burden on healthcare system and increasing risk of mortality. Mobile applications (apps) can be a promising approach to facilitate diabetes self-management. An increasingly utilized approach to facilitate engagement with mobile health (mHealth) technology is to involve potential users in the creation of the technology.

Objective: The aim of this study was to use co-design for type 2 diabetes mellitus (T2DM) self-management mHealth development.

Methods: Three rounds of iterative rapid prototyping panel sessions were conducted with a total of 9 T2DM participants in an Asian setting between Oct 2020 and April 2021. The participants were recruited through convenience sampling. For each round, feedback was gathered through qualitative interviews, and the feedback was used as a reference by the development team to develop and test a more refined version of the app in the next round. Transcribed semi-structured interview data was analyzed thematically using an inductive approach.

Results: Participants' ages ranged from 40 to 69 years. Data saturation was reached, with no new themes emerging from the data. During the sessions, the participants expressed a variety of concerns and feedback on T2DM self-management using EMPOWER app and raised suggestions on the features of ideal T2DM self-management app. Important features include 1) reminders and notifications for medications, 2) Bluetooth integration with glucometers and blood pressure machines to minimize manual entry, 3) enlarged local food database including information on sugar content and recommendations for healthier options, 4) one touch for logging of routine medications and favorite foods, 5) export function for data sharing with physicians. Overall inputs concerned aspects such as user-friendliness of the app, customization possibilities, and educational content for the features in the mobile app.

Conclusion: In this study, we explored users' opinions on a T2DM self-management mobile app using co-design approach. This study adds to the growing body of literature on co-designing behavioral mHealth interventions and can potentially guide researchers in mobile app design for other chronic conditions.

Keywords: type 2 diabetes mellitus, mHealth, mobile app

Introduction

Diabetes is a chronic disease that is rising across the globe, affecting approximately 537 million adults[1,2] and accounting for 1.5 million of the total deaths globally in 2019.[3] According to the National Health Survey 2019, the prevalence of self-reported diabetes, among Singapore residents aged 18 to 74 years was found to be 6.9%,[4] in which the prevalence of type 2 diabetes mellitus (T2DM) among Singapore residents aged 18 to 69 years was anticipated to reach 15% by 2050.[5] Diabetes can result in microvascular complications (ie, cardiovascular disease), macrovascular complications (ie,

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neuropathy, nephropathy, and retinopathy), and diabetes-related depression, all of which increase the risk of mortality, disability and decrease quality of life.[6] Poor lifestyle habits[6] and inadequate adherence to medications for diabetes were commonly observed.[7–9] These behaviors could lead to inadequate glycemic control,[10] contributing to the burden of diabetes such as increased medical cost and increased mortality rates.[11]

To effectively manage T2DM and prevent its complications, good self-management behaviors, in which patients actively involve themselves in their own care, need to be further emphasized as an essential role in complementing clinical care. Self-management interventions have been found in studies to increase medication adherence[12] and to have clinically important benefits on glycemic outcomes[13,14] and mental health outcomes.[14] In fact, mobile applications (apps) have been utilized to deliver effective self-management support through supporting healthy lifestyle changes[15–17] and encouraging medication adherence.[18,19] However, low engagement with the apps may hamper users from reaping the benefits of the mobile apps.[20,21] Having users to participate in the design process may result in a higher level of empowerment and engagement,[22] which would assist mobile health (mHealth) apps in effectively supporting T2DM patients.[23]

Co-design refers to the active involvement of users in the creation of innovative products.[24] By embracing users' inputs, it can aid app designers in developing an app that better meet users' requirements.[25,26] Although co-designing has been proven to substantially improve patients' experiences,[27] increase user-friendliness and appeal of a mobile app,[28] only limited studies on co-designing with users of a diabetes-related mobile app are available,[29–32] which may be because co-design is still in developing stage in the area of healthcare.[27] Furthermore, only limited qualitative studies on user engagement with mHealth apps have been undertaken in Asian settings.[33] Previous studies have demonstrated that the effectiveness of digital interventions may be potentially influenced by culture.[34,35] Among the qualitative studies that were conducted on patients' perspectives of mHealth apps for diabetes management, the majority of them were conducted in non-Asian settings.[17,36–40] In addition, our previous study has indicated the potential of nudges to promote T2DM self-management,[41] and literature on digital nudging for T2DM self-management is scarce.[42] Hence, this study aims to use co-design for T2DM self-management mHealth development.

Methods
Study Design
A co-design approach was used, which utilized qualitative methods in rapid prototyping process (RPP). We adopted the co-design framework suggested by Sanders & Stappers[43] in this study. A rapid prototyping approach was utilised to obtain input from users to quickly create and improve the design of app prototypes.[44] This approach enables developers to build, test and make revisions rapidly through feedback loops to ultimately yield a superior and functional prototype.[45]

Ethical approval for this study was obtained from SingHealth Centralized Institutional Review Board (CIRB Ref No.: 2019/2468). Informed consent was obtained from the participants prior to their involvement in the study.

EMPOWER App
Initial design ideas of the EMPOWER app were derived from focus group discussions (FGDs) with 29 T2DM patients and 56 healthcare professionals previously.[41] These FGDs explored their interactions with mHealth apps that were available on the market, and their preferences for apps that promote healthy lifestyle behavior. The initial wireframes for the EMPOWER app were also developed in accordance with the Behavior Change Wheel[46] to raise users' awareness of how their lifestyle behaviors could affect their condition and for the app to effectively encourage action for behavior change.

Following that, the app prototype was developed and introduced in Round 1. Four features (ie, Activity Logging, Medication Plan, Report, Patient Diary) were available in the app initially. Subsequently, another 4 features (ie, Appointment Management, Gamification, Goals Setting, Educational Materials) were incorporated before Round 2. Notification feature was then added before Round 3. These features are described in Table 1.

Table 1 EMPOWER App Features

Features	Description
Activity Logging	Input blood glucose readings, food intake, medications taken, and weight logs. Physical activity data will be tracked by the Fitbit tracker.
Report	Graphs to monitor blood glucose levels, calories intake, medication adherence, weight, steps taken, and calories burnt.
Patient Diary	View past data of blood glucose levels, foods taken, medication taken, weight, and physical activity logs.
Medication Plan	Set up scheduled medications.
Educational Resources	Access to educational resources such as articles and videos on diabetes management.
Goal Setting	Set goals for blood glucose levels, calories intake, medication adherence, weight, calories burnt and number of steps.
Gamification	Gain points through a bingo game, and upon accumulation of sufficient points, users will be able to redeem rewards such as vouchers.
Appointment Management	View date, time, location, and purpose of appointments.
Chat	Chat window to interact with doctors at a specific time slot.
Notifications	Personalized push notifications generated based on the user's inputs.

Participants

We recruited participants for the RPP from the original pool of participants who participated in previous studies (manuscripts under review). Eligible participants included those who were 40 years old and above and had the diagnosis of T2DM. Patients who presented diabetes-related complications or gestational diabetes were excluded. We recruited participants who were more vocal and ensured that both technologically savvy and non-technologically savvy participants were included. Out of the 9 participants who were approached, all nine participants agreed to participate in the RPP sessions. However, one participant dropped out after Round 1 as she was concerned that she was not technologically savvy enough to test the app. Due to scheduling conflicts, only 3 participants were able to participate in all 3 rounds. The number of participants who were involved in Rounds 1, 2, 3 were 7, 5, 5, respectively. Each participant was rewarded $40 per session for their participation.

Data Collection

Prior to the RPP sessions, the participants were asked to use the app. We provided 10-minute free-and-easy app testing before commencing the RPP session if any participants have not tested the app. For each RPP session, feedback was gathered which was used as a reference by the development team to develop and test a more refined version of the app in the next round. The purpose and scope of the app were refined, possible pitfalls were addressed, new updates were introduced briefly, and design features were discussed.

Three trained interviewers conducted the sessions through a video conferencing software (Zoom). The sessions were audio-recorded, and each session lasted between 75 and 110 minutes. We conducted 3 rounds of RPP sessions in total. The sessions were facilitated by using a semi-structured interview guide (Supplementary Table 1) for each round. Qualitative data was collected between 30 Oct 2020 to 27 April 2021.

Data Analysis

Qualitative data was analyzed using a thematic analysis approach using NVivo 12 Software (QSR International). An inductive approach was performed to develop codes and themes without trying to fit into an existing framework. The 6-step thematic analysis approach (familiarizing with data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, as well as producing the report) recommended by Braun and Clarke[47] was used.

Results

Demographics of Participants

In total, there were 6 female participants (67%) and 3 male participants (33%) who participated in the RPP sessions. Data saturation was reached, with no new themes emerging from the data. The participants ranged in age from 40 to 69 years, with the most common age range being 60 to 70 years (56%). Further participant characteristics are summarized in Supplementary Table 2.

Prototype Development

The key themes, their definitions and quotes from participants are summarized in Supplementary Table 3 and Supplementary Table 4. The suggestions offered by participants, how the prototypes reflected the suggestions, and potential integration work are summarized in Table 2.

Table 2 Suggestions of EMPOWER App and Solutions

Suggestions	Solutions or Possible Solutions Came Up by the Development Team	Change Implemented
Physical Activity Logging		
Backdating of physical activity logging	Allow selection of previous dates and timings when inputting logs	Yes, after round 2
Blood Glucose Logging		
To be able to input comments for blood glucose logs	Introduce text box to allow optional input of qualitative comments about a blood glucose reading	Yes, after round 2
To include two blood glucose units in the app (ie, Millimole per litre and milligram per deciliter)	To include two blood glucose units (ie, Millimole per litre and milligram per deciliter)	No, possibly in future builds
Glucometer-connected app	Connect to glucometer and send data to EMPOWER app	No, possibly in future builds
Food Logging		
To be able to input half portion of food	Allow manual input of 0.5 as portion size when keying in food logs	Yes, after round 1
To find the food item consumed but was not available in the app	Add section to allow manual input of details for each individual food item	No, possibly in future builds
Guideline for healthier food choices	Show healthier choice symbol or any equivalent diabetic-friendly certification for each food item	No, possibly in future builds
Medication Plan and Logging		
To be able to input half a tablet	Allow manual selection of 0.5 as a unit difference when indicating number of tablets per log	Yes, after round 1
To be able to input non-prescription medications, complementary health products, supplements in medication plan	Add a section to allow optional, manual input of custom medications, including name and select dosage	Yes, after round 3
To be able to input other prescriptive medications besides diabetes medications	Add a section to allow optional, manual input of custom medications, including name and select dosage	Yes, after round 3
Physical Activity Logging		
Other fitness trackers, in addition to the Fitbit tracker, should be able to sync with the EMPOWER app	Allow synchronization with more fitness trackers	No, possibly in future builds
Notifications		
Notifications to remind users to take their medication(s) and complete their medication logging	Allow users to set reminder and select days and timing of notifications in medication plan. Push notifications will be sent to users at the selected date and time.	Yes, after round 3

(*Continued*)

Table 2 (Continued).

Suggestions	Solutions or Possible Solutions Came Up by the Development Team	Change Implemented
Notifications to remind users of their upcoming appointment(s)	Send push notifications to users before appointment.	No, possibly in future builds
Alert doctors and caregivers when sugar reading exceeds the acceptable range	Add push notifications based on blood sugar reading for doctors and caregivers	No, possibly in future builds
Gamification		
Educational games in the game center to increase knowledge on diabetes control such as pop quiz and word builder to form names of diabetes medications	Add educational games in the game center	No, possibly in future builds
Type of Rewards: • Discount on medical bills • Discount on diabetes supplies such as glucose strips • Grocery vouchers	Add catered rewards for users	No, possibly in future builds
Chat		
To be able to interact with personal doctor	Introduce a chat-based feature to facilitate scheduled, synchronous communications with doctors	No, possibly in future builds
Chat window to communicate with fellow patients	Introduce a chat-based feature to facilitate communication among users	No, possibly in future builds
Educational Resources		
Additional educational materials to contain information such as: • Advice on how to manage diabetes • What to do when someone goes hypoglycemic or hyperglycemic • Names of diabetes medical journals and where to access them • Time of day to take diabetes medications, what they do to the body and side effects • Diabetes medications in development and new diabetes medications • Proper way to inject insulin and insulin safety tips • Places to buy affordable insulin needles • Places where diabetic-friendly foods can be purchased at a reasonable price • List of diabetic-friendly foods, beverages, and diabetic-friendly ingredients (eg, natural sweeteners) • Healthier food options • Encouraging, positive and motivating posts on diabetes	Add additional educational resources catered to the users	No, possibly in future builds
Others		
To be able to view HbA1c test results in the app	Retrieve lab results public health systems	Yes, after round 1 (simulated lab results)
To be able to view lipid panel results in the app	Retrieve lab results public health systems	Yes, after round 1 (simulated lab results)
Guide to teach new users how to use the app	Introduce instruction manual, educational guide video or help portal (website)	Yes, after round 1

App Features
Blood Glucose Logging

In Round 1, a participant pointed out that a glucometer-connected mobile app could eliminate the need for users to enter blood glucose readings manually. In addition, as blood glucose levels can be measured in two different units – millimoles per litre (mmol/L) and milligrams per decilitre (mg/dL), a participant enquired whether both units could be incorporated in the app. In Round 2, a participant who received insulin treatment stated that regular inputting of blood glucose readings helped him in titrating his insulin dose. In round 2, another participant emphasized the importance of adding comment box for blood glucose readings to understand the cause of fluctuations in blood glucose levels eg, due to consumption of "sinful food".

Food Logging

Participants liked the availability of local food options, and the capacity to log in as many meals as they consumed throughout the day. As the EMPOWER app allowed users to view a food's nutritional information, it could advise users to control portion sizes. In Round 2, one participant stated that the provision of carbohydrate content information aided him in meal planning. However, due to the extensive food options available in the database, selecting a food item that matched what they had consumed became more complicated. Despite the extensive food options available in the database, three participants pointed out that not all food options, such as home cooked meals, were in the database. Fortunately, the participants understood that they could select a similar option or enter the food details manually. Other suggestions raised by the participants to improve the app included providing a list of healthier options and displaying the sugar content of foods.

Medication Plan and Logging

Suggestions included allowing backdating medication logs, permitting logging of partial doses of medication, including non-diabetes medications and including complementary health products. In Rounds 1 and 2, three participants also enquired whether they could record medication by simply tapping on a button instead of typing in the medication name every time.

Physical Activity Logging

Since the physical activity logging feature required a connection to a fitness tracker, four participants hoped that a tracker would be provided to motivate their use of the app. In Round 3, two participants expressed concern that the EMPOWER app could only pair with a single brand of tracker, given that different brands of tracker wearables are available in the market.

Patient Diary

Participants mentioned that the ability to view their previous entries using the diary function is beneficial to remind them of their previous inputs.

Report and Goal Setting

All participants valued the significance of blood glucose trending and food tracking in the report section to determine whether they were on track. If they were not, it would nudge them to take the necessary steps to control their condition. If there was spike in the trend of blood glucose levels, they could find out which meal that caused it and subsequently adjust their meal intake accordingly. The participants also valued the ability of the app to export their trends for their doctor to view and better understand their situation.

As the EMPOWER app allowed users to view their progress over a period, they might experience negative or positive emotions depending on the outcome of the trend. For example, participants stated that the readings served as a reminder and encouragement to persevere and strive for their goals. However, users may become demotivated when goals were not met. In Round 3, one participant expressed that while progress that fell short of his expectations could dampen his spirits, it would remind him to keep going at a steady pace.

Notifications

Participants valued the notification feature as it would serve as a reminder to take their medications. In Rounds 1 and 2, two participants mentioned that they envisioned the app to alert their doctor or caregiver when their readings were significantly outside of the acceptable range.

Appointment Management

Although all participants found the appointment management feature useful, two participants in Round 1 voiced out that this was a duplication of function in other health apps. They would prefer an integrated app to avoid the need to use multiple apps.

Gamification

This gamification feature had received an unenthusiastic response from most participants. In Round 1, one participant that expressed his disinterest asserted that his only purpose of using this app was to manage his condition. In Rounds 2 and 3, participants mentioned that they would be enticed to play the game if the rewards included grocery vouchers, discounts on their medical bills or discounts on glucose strips. In Round 3, participants suggested including educational games to raise users' level of diabetes knowledge.

Educational Materials

Even though the educational resources available were limited, most participants were contented with this feature. The participants mentioned that the educational resources appeared useful, informative, and reliable. However, in Rounds 1 and 2, three participants stated that they were already well informed about their condition and that the educational resources would be better suited for patients newly diagnosed with diabetes. Participants also suggested the desired information to be included in the app, including information on diabetes management, diabetes medication, insulin injection technique, diabetic-friendly foods and beverages, and places to purchase affordable diabetes supplies.

Chat

In Round 1, three participants expressed skepticism when asked about the possibility of a chatting platform with doctors, raising concerns such as whether time required to receive reply. One suggestion raised was to have a chatting platform among patients with diabetes for emotional support and sharing of information on diabetes.

General Feedback and Concerns

When asked whether they would use the EMPOWER app daily, most participants declined or expressed uncertainty about their ability to do so, citing reasons such as a busy lifestyle and data to be inputted being too repetitive. The participants also raised the concern whether app will be suitable for older patients who may not be technologically savvy. Other concerns included the risk of patient confidentiality being compromised, as well as the lack of HbA1c and lipid panel results in the EMPOWER app.

Despite these concerns, participants stated that they would like their family members and friends, including people with diabetes, those with poor diabetes control, pre-diabetics, and even non-diabetics, to use the app to monitor their blood glucose levels and overall health.

Discussion

In this study, we explored users' opinions on utilizing the EMPOWER app for diabetes self-management through RPP to improve the design of the app. Adopting a co-design approach enabled insight into users' perspectives and experiences with the mobile app on diabetes self-management with sufficient depth to understand their concerns. Our study also demonstrated the potential of using app notifications as nudging for patients with T2DM, which may be a useful addition to the scarce literature on digital nudging for T2DM self-management.[42] The suggestions and potential solutions derived from this study may be useful for other researchers and app developers working on mHealth tools for chronic disease management. Our findings indicate that using an iterative co-design approach employing qualitative methods allows comprehensively examination of app utility, usability, and acceptability. Similar technique has been employed in other studies.[48,49] Although the use of qualitative methods reflects a solid approach to ascertain usability, additional methods need to be considered when refining the app in the future research. For example, analysis of app usage data can provide useful information in terms of engagement with mobile app.[50]

Our findings reveal that app functionality and usability were important factors affecting the user experience of the mobile app. One consistent concern raised by participants was that effortful manual input of blood glucose, food and medication logs may hamper the use of app, which is also seen in another study.[51] Throughout the 3 rounds of RPP sessions, we received feedback and suggestions to improve the mobile app. Due to the time and resource constraint for app development for the next phase of the study,[52] we have only incorporated a portion of the suggestions and potential solutions derived from this study based on complexity and needs of the users. Together with other potential behavior

change interventions such as health coaching[53,54] and motivational interviewing,[55,56] the unimplemented suggestions and solutions in this study will be considered during subsequent updates of the mobile app.

Our results highlight that the availability of relevant informative content in the mobile app is in demand and critical, which aligns with findings from other studies.[16,38,40,51,57] Furthermore, as people can be exposed to misinformation through the internet, having access to reliable information on diabetes management is especially crucial.[16,40,51] However, this study provides valuable insight into the potential negative impact of mHealth on psychological wellbeing. Consistent with other evidence,[51] our results showed that the information presented in mobile app can have counterproductive emotional and motivational consequences. For example, users may become demotivated when goals were not met. A potential solution to mitigate negative emotional consequences from mHealth may be through developing a communication platform among the patients for social support.[15,40,58–60]

Similar to other studies,[51,61–64] our findings also highlighted users' concern on app privacy and the disclosure of personal records. To foster trust and ensure transparency, app developers should provide users with clear private policy outlining the key data practices, how and what kind of data will be collected, handled, and stored.[61,65]

This study used convenience sampling to recruit participants who were willing to participate in multiple rounds of RPP sessions which may affect the representativeness of the sample. However, even though the sample size was small, the participants varied with respect to age, gender, educational level, and employment status which may support the generalizability of the findings from this study. As some participants had not used the app prior to the sessions or had only used it briefly throughout the duration of data collection, user experience for these participants was limited. During the sessions, the interviewers made a significant effort to guide the participants through the app so that they could provide more detailed feedback on the app.

Conclusion

In this study, we explored users' opinions on a T2DM self-management mobile app using a co-design approach. Participants provided their perspectives on the usability, functionality, and acceptability of the mobile app together with suggestions for improvement such as the importance of simplifying logging process to enhance users' sustained engagement. Our study also highlights the value of relevant informative content in mHealth tools for diabetes management. The suggestions and potential solutions derived from this study may be useful for other researchers and app developers working on mHealth tools for chronic disease management. This study adds to the emerging literature on employing a co-design approach to design mHealth technology for T2DM self-management by incorporating user feedback and concerns in the development of mobile apps, and the study design can be adapted when designing mHealth technology for other populations.

Data Sharing Statement

The data used in this study will be made available by the corresponding author upon reasonable request.

Ethics Approval and Informed Consent

The SingHealth Centralized Institutional Review Board approved this study (Ref No: 2019/2468). We obtained informed consent from all participants prior to the commencement of the study. The participants' informed consent included publication of anonymized responses.

Disclosure

The authors declare that they have no other competing interests.

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