Self-Care Oriented Smartphone Apps for Type 2 Diabetes: A Comparative Analysis

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***Abstract**. Type 2 diabetes can cause serious health complications due to sub-optimal blood glucose levels, so patients at risk need to monitor their lifestyle and improve self-care. Mobile apps for smartphones are the right tools for this. To provide patients with an evidence-based mobile app, we conducted a review of mobile stores. We used the AADE7 framework to assess the presence of self-care behavioural functions. uMARS scale was used to rate the overall quality of smartphone apps. Specifically, we identified 12 relevant apps and found that they included only 51 out of 88 possible behavioural features for self-care. In addition, most of the apps were rated as suboptimal in terms of inclusiveness, functionality, aesthetics and information. Based on the uMARS scoring scale, the average quality rating of the smartphone apps was 3.76. The highest average quality scores were given to forDiabetes: diabetes self-management app. Overall, we argue that diabetics can better control themselves with smartphone apps that implement enough relevant behavioural features for self-management.*

Keywords. mobile phone; mobile health; smartphone application; health behavior; application quality

1 Introduction

Diabetes is a slowly progressing chronic disease that affects millions worldwide and kills over one million people yearly, making it the ninth leading cause of death (Bratzke et al., 2015; Jacoby, 2019; Karimy et al., 2016). There exist two types of diabetes. *Type 1 diabetes mellitus* is caused by the autoimmune destruction of beta cells (Salsali & Nathan, 2006) and is the most common type of diabetes in children and adolescents (Dowling, 2021). In contrast, *Type 2 diabetes mellitus* (T2DM) is caused by resistance to insulin action, usually due to obesity and lack of insulin secretion. Concretely, T2DM disrupts blood glucose levels, which can lead to acute and macrovascular chronic complications (Nickerson & Dutta, 2012; Yau et al., 2012). Therefore, T2DM patients must constantly monitor their blood glucose levels to control them (Nyenwe et al., 2011; Shrivastavva et al., 2013) and focus on self-care to prevent complications.

However, high-quality self-care in the context of T2DM is not trivial and requires knowledge about the disease and its management, behavioral interventions such as diet and insulin adjustments, and emotional aspects such as self-efficacy (Bigelow & Freeland, 2017; Siguroardóttir, 2005). First, knowledge about T2DM is a form of health literacy, a *social determinant* of health that can be influenced by social policies (Braveman & Gottlieb, 2014) and that is important for people to control their health (Kendir & Breton, 2020). The Internet has significantly impacted health literacy by increasing access to online health information (Lee et al., 2021). Second, behavioral interventions require careful monitoring of blood glucose levels to avoid, identify, and treat hypo- and hyperglycemia, and prevent morbidity and mortality (Asgari & Nazari, 2019; Rezaei et al., 2019). Third, self-care adherence can be stimulated by actively involving patients in managing their condition (Izahar et al., 2017), thus improving their satisfaction, happiness, and overall quality of life (Amelia, 2018).

Mobile health (m-health) offers promising solutions for maintaining self-sufficiency in chronic diseases such as T2DM (Rossi & Bigi, 2017; Scott et al., 2020; Srivastava et al., 2015). By providing customized information, instructions, graphics, and reminders, smartphone apps can improve self-care behavior, health knowledge, and commitment (Asgari & Nazari, 2019; Gardsten et al., 2017; Adu et al., 2020; Bene et al., 2019; Kebede & Pischke, 2019). Furthermore, smartphone apps can simplify remote health management by providing tailored self-care recommendations and facilitating communication between patients and care providers (Liu et al., 2020).

Nevertheless, smartphone apps targeting T2DM patients vary in supported features, availability, required device type or operating systems, etc. (Zhang et al., 2020). So far, a clear overview, comparison, and evaluation of these smartphone apps are missing. Our systematic review fills this gap: we assess and compare apps in terms of supported self-care behavior functions and overall quality. Moreover, we point out shortcomings in currently available smartphone apps and provide suggestions for improvement.

This app review aimed at providing patients with type 2 diabetes with relevant and evidence-informed mobile applications for self-care and disease management.

2 Methods

We formulated our research goals with the PIO model (Polit & Beck, 2012): the *target population* (P) consisted of T2DM patients older than 18; the *intervention* (I) was to identify smartphone apps that aim to control T2DM and record measured glucose values, daily activity, dietary intake, and medications; and the *outcome* (O) was an assessment of apps regarding self-care behavior functions and quality. This section describes how we collected, selected, and assessed apps that target T2DM patients. Our assessment encompasses both supported self-care behavior functions and overall quality.

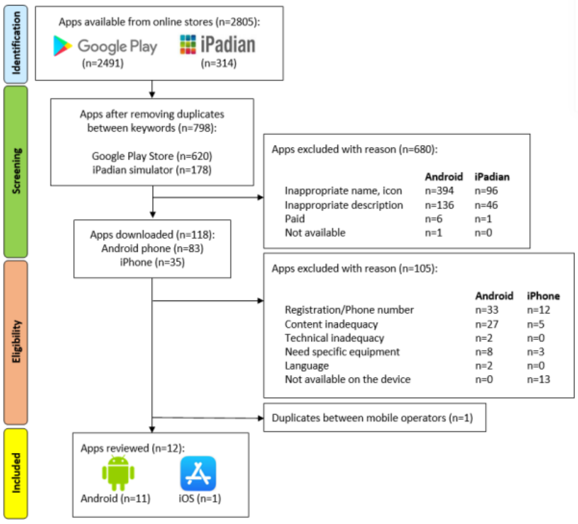

Figure 1. Flow diagram of our search process.

2.1 Search Strategy and Selection Process

Following the PRISMA guidelines (Moher et al., 2009), we systematically searched for smartphone apps in the Google Play Store (Android) and the iPadian simulator (iOS). In January 2021, the first two authors independently searched for apps with the keywords "diabetes" and "T2DM" and transferred the details of hits to Microsoft Excel. Then, they screened the name, icon, and description of collected apps based on preset inclusion criteria, consulting a third researcher in case of disagreement. The inclusion criteria were as follows: the used language was English, no registration or connection devices were required, no in-app purchases were necessary, and the app fostered T2DM self-care and allowed to enter the health measurements mentioned in our *intervention* criterium.

We only included mobile apps that are not paid for and do not require registration or integration, as we wanted to give all patients with type 2 diabetes the same options for use as much as possible. Using mobile apps requires technical skills such as setting up an account, logging into the mobile app, which is too complex for those who are less technically proficient (Campos-Castillo & Mayberry, 2022; Nelson et al., 2022). Participants who have a lower income or are less health literate are less likely to have a smartphone and use mobile apps (Nelson et al., 2022). Mobile health literacy has a direct impact on knowledge and use of mobile technology, which in turn affects patient health outcomes (Guo et al., 2021).

Only the Android version was included for apps available on both Android and iOS. Finally, we installed all included apps on a Huawei Pro 20 (Android 9.0) or an iPhone 7 (iOS 12.3.1).

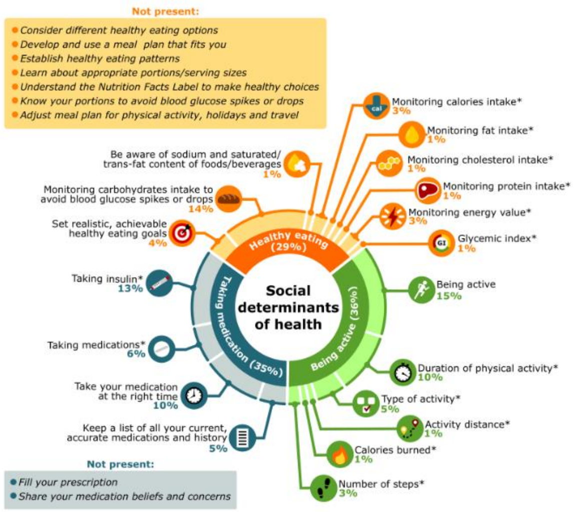

Figure 2. Present self-care behavior functions in *Awareness of social determinants of health.*

2.2 Assessing Self-Care Behavior Functions

The first two authors independently assessed the presence of self-care behavior functions according to the AADE7 framework (AADE, 2020; Burson & Mran, 2014; Eaton, 2020; Ye et al., 2018), which classifies self-care behavior functions into three main categories. First, **Awareness of social determinants of health** contains three subcategories: *healthy eating* (16 functions), *taking medication* (6 functions), and *being active* (6 functions). Second, **Integration of technology into self-care** encompasses *monitoring* (16 functions). Third, **Role of the diabetes care and education specialist** contains three subcategories: *problem-solving* (3 functions), *risk reduction* (31 functions), and *healthy coping* (10 functions). Found self-care behavior functions not yet part of the AADE7 framework were added to the most suitable category (marked with * in Figures 2 and 3).

2.3 Assessing Overall Quality

To assess the overall quality of smartphone apps, we used the uMARS scale (Stoyanov et al., 2016), which contains four constructs: *Engagement*, *Functionality*, *Aesthetics*, and *Information*. First, *Engagement* assesses whether apps are fun and interesting to use, interactive, and allow for customization. Then, *Functionality* evaluates the apps' performance, ease of use, navigation flow, and gestural design. Next, *Aesthetics* evaluates the layout, graphical form, and visual appeal. Finally, *Information* assesses whether the provided information is sufficient and of high quality, comes from a credible source, and is displayed visually. Two graduate nurses, experienced with managing chronically ill patients, used all apps for a few minutes and then rated the four uMARS constructs with scores ranging from 1 (inadequate) to 5 (excellent). The final uMARS quality score is the average of these four constructs, ignoring questions answered with N/A (not applicable).

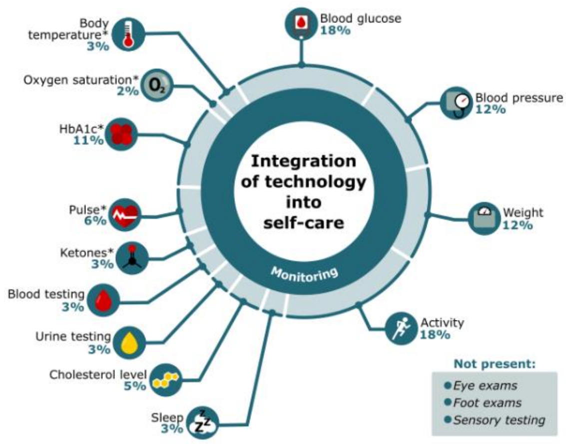

Figure 3. Present self-care behavior functions in *Integration of technology into self-care.*

3 Results

Figure 1 shows the PRISMA flow diagram of our search process. In total, 2805 smartphone apps matched our search queries. After removing duplicates and eliminating apps not complying with our inclusion criteria, 118 apps remained. After downloading all these apps on an Android or iOS smartphone, we removed 106 of them from our sample due to mandatory registration (e.g., email, phone number; n=45), substantive inadequacy (e.g., did not contain a component for tracking blood sugar, diet, activity, and medications; n=32), technical inadequacy (e.g., malfunction; n=2), need for additional technological devices (e.g., blood sugar meters that transfer data to smartphones via Bluetooth; n=11), non-English language (e.g., Spanish; n=2), and unavailability for the used device (e.g., only for iPad; n=13). Ultimately, our screening process resulted in 12 smartphone apps suitable for evaluation: four apps for both platforms (33%), one for iOS only (8%), and the remaining seven for Android only (58%). Four apps (33%) were classified under the *Health & Fitness* category in the mobile store, the others under *Medical*.

3.1 Self-Care Behavior Functions

Figures 2 to 4 visualize self-care behavior functions present in the reviewed smartphone apps, categorized according to the AADE7 framework.

Table 1 presents the distribution of the self-care behaviour functions into three main categories within their sub-categories.

Awareness of social determinants of health (see Figure 2) contains 28 unique self-care behavior functions, but we only found 19 of them (68%) in the reviewed apps. In total, apps supported only 78 out of

$12 \times 28 = 336$ functions, which is about 23%. The most common functions were *being active*, *monitoring carbo-hydrates intake*, and *taking insulin*: they were present in 12/12 (100%), 11/12 (92%), and 10/12 (83%) apps, respectively. Overall, *forDiabetes: diabetes self-management app* contained the widest range of self-care behavior functions.

Table 1. Self-care behavior functions

Awareness of social determinants of health	
Being active	28/78 functions
Taking medication	27/78 functions
Healthy eating	23/78 functions
Integration of technology into self-care	
	65/192 functions
Role of the diabetes care and education specialist	
Problem solving	12/148 functions
Risk reduction	101/148 functions
Healthy coping	35/148 functions

Integration of technology into self-care (see Figure 3) contains 16 unique self-care behavior functions and we recorded 13 of them (81%) in the reviewed apps. Yet, in total, apps supported only 65 out of the $12 \times 16 = 192$ functions; about 34%. All apps allowed to monitor blood glucose and activity, together accounting for 36% (24/65) of all recorded functions. Furthermore, 8/12 apps (67%) allowed to monitor both blood pressure and body weight, together accounting for 24% of all recorded functions. Finally, 7/12 apps (58%) supported monitoring HbA1c (i.e., glycosylated hemoglobin), accounting for 11% of all recorded functions. Two exemplar apps in this category were the *WeCheck -Diabetes lifelog, Blood Glucose Level* and the *Smart e-SMBG-Diabetes lifelog, Blood Glucose* apps, which allowed to monitor blood glucose levels, weight, body fat, HbA1c, feelings, mood, and hypoglycemia awareness.

Role of the diabetes care and education specialist (see Figure 4) includes 44 unique self-care behavior functions. However, we only found 18 of them (41%) in the reviewed apps, which supported 148 out of $12 \times 44 = 528$ functions (28%). In the *problem solving* subcategory, 2/3 self-care behavior functions (67%) were represented: 11/12 apps (92%) facilitated problem identification, but only 1 app (8%) encouraged patients to act. Furthermore, r*educing risks* represented 14/31 functions (45%) and all reviewed apps (12/12) monitored food and medication and advised to take prescribed medications and measure blood sugar. Finally, *healthy coping* represented 3/10 functions (30%): all smartphone apps (12/12) encouraged body movement and physical activity, and 11/12 apps (92%) allowed journalling. Overall, the *WeCheck-Diabetes lifelog, Blood Glucose Level* and the *Smart e-SMBG-Diabetes lifelog, Blood Glucose* apps supported the most self-care behavior functions.

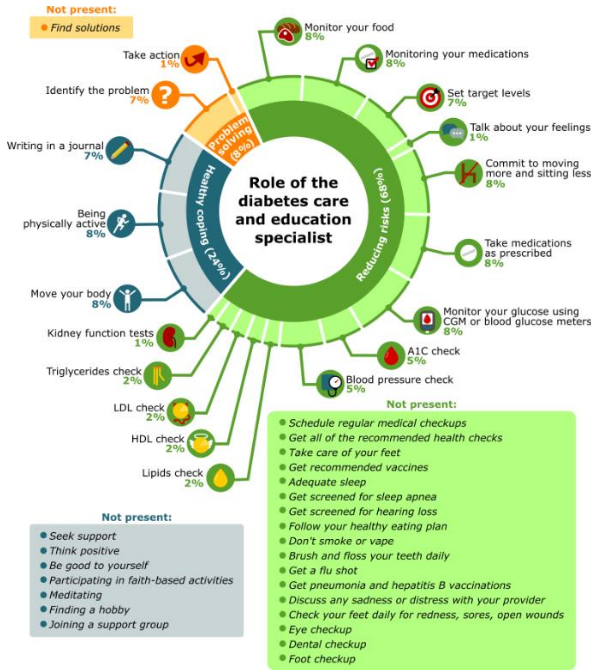

Figure 4. Present self-care behavior functions in *Role of the diabetes care and education specialist*.

3.2 Overall Quality

Based on the uMARS scoring scale, the average quality rating of the smartphone apps was 3.76/5 (SD 0.31). The highest average quality scores were given to *forDiabetes: diabetes self-management app* (4.54, SD 0.33) and *Diabetesdagboka* (4.09, SD 0.10). Overall, the lowest rated category was *Aesthetics*, scoring 3.68 on average (SD 0.47), and *Engagement* received the highest average rating (3.86, SD 0.34).

Regarding engagement, the most interesting and interactive smartphone app was *forDiabetes: diabetes self-management app* (4.5, SD 0.14), whereas Diabetes Journal (3.3, SD 0.42) got the lowest score. Regarding functionality, only 3 smartphone apps scored at least 4.00: *forDiabetes: diabetes self-management app*; *WeCheck -Diabetes lifelog, Blood Glucose Level; Smart e-SMBG -Diabetes lifelog, Blood Glucose*. The *SiDiary Diabetes smartphone app* was rated for the least functional application (3.50, SD 0.71*). SiDiary Diabetes* was considered the least aesthetically pleasing smartphone app (2.67, SD 0.47). *forDiabetes: diabetes self-management app* was rated with the highest score for information in the smartphone app (4.88, SD 0.18).

4 Discussion

Smartphone apps facilitate chronic disease management and thus show great potential for self-care education (Zhang et al., 2020), improving motivation (Fijačko et al., 2020) and reducing patient experience

(Lu et al., 2018), assisting with strict treatment requirements (Lee 2014), and reducing the cost of care (Lewinski, et al., 2019). However, a lack of knowledge about their actual use (Trawley et al., 2017), insufficient evidence of effectiveness in changing behavior (Milne-Ives et al., 2020; Zhao et al., 2016), and insufficient evidence of clinical precision limit their effectiveness (Fleming et al., 2020).

We systematically assessed smartphone apps for T2DM patients regarding supported self-care behavior functions and overall quality. Overall, we found 12 useful apps for T2DM self-care with above-average quality but lacking self-care behavior functions. They included only 51 of the 88 possible self-care behavior functions. The least well represented are the functions that focus on integrating the role of the expert in the care and education of patients with diabetes.

App name	Engagement	Functionality	Aesthetics	Information	Average
forDiabetes: diabetes self-management app	4.50 (0.14)	4.13 (0.53)	4.67 (0.47)	4.88 (0.18)	4.54 (0.33)
Diabetesdagboka	4.20 (0.28)	3.88 (0.18)	4.17 (0.24)	4.13 (0.18)	4.09 (0.1)
Diaguard: Diabetes Tagebuch	4.20 (0.28)	3.88 (0.53)	4.17 (0.24)	3.38 (0.18)	3.90 (0.10)
Diabetes:M - Management & Blood Sugar Tracker App	3.90 (0.71)	3.88 (0.53)	3.50 (0.71)	4.13 (0.53)	3.85 (0.62)
WeCheck -Diabetes lifelog, Blood Glucose Level	3.80 (0.28)	4.13 (0.18)	3.50 (0.71)	3.63 (0.18)	3.76 (0.25)
Smart e-SMBG -Diabetes lifelog, Blood Glucose	3.80 (0.28)	4.13 (0.18)	3.50 (0.71)	3.63 (0.18)	3.76 (0.25)
MEET ME @7 - Diabetes Self-management Tool for Patients and Caregivers	3.90 (0.71)	3.88 (0.18)	3.67 (0.47)	3.50 (0.35)	3.74 (0.43)
SmartLog	4.10 (0.42)	3.63 (0.18)	3.50 (0.71)	3.38 (0.53)	3.65 (0.46)
BG Monitor Diabetes	3.60 (0.57)	3.38 (0.18)	3.83 (0.24)	3.38 (0.53)	3.55 (0.29)
Betes - Your Diabetes Diary	3.50 (0.71)	3.75 (0.35)	3.50 (0.71)	3.38 (0.53)	3.53 (0.57)
Diabetes Journal	3.30 (0.42)	3.88 (0.18)	3.50 (0.71)	3.25 (0.71)	3.48 (0.42)
SiDiary Diabetes Management	3.50 (0.14)	3.50 (0.71)	2.67 (0.47)	3.63 (0.18)	3.32 (0.07)
Overall mean (SD)	*3.86 (0.34)*	*3.83 (0.23)*	*3.68 (0.47)*	*3.69 (0.45)*	*3.76 (0.31)*

Figure 5. uMARS mean scores for all included smartphone apps. Column-wise maximal and minimal values are highlighted in green and red, respectively.

4.1 Integrating More Diverse Self-Care Behavior Functions in Apps

We discuss the three AAED7 subcategories of self-care behavior functions separately.

4.1.1 Awareness of Social Determinants of Health

Of all self-care behavior functions, existing apps best support the awareness of social determinants of health. This is a positive finding because physical activity and proper diets are essential to prevent complications due to T2DM (Anjana & Mhan, 2016; Kim et al., 2022).

All smartphone apps allow recording physical activity, for example, activity type and duration. However, only one app shows an estimate of the number of calories consumed during physical activity. This is because the apps we reviewed are not sport tracking apps but are instead tailored towards T2DM self-care. Most apps allow monitoring carbohydrate intake to avoid fluctuations in blood glucose and thus hyper- or hypoglycemia. Yet, no existing apps monitor meal size or explain dietary labels. Adding such functionalities would make it easier for T2DM patients to compose a proper diet and encourage them to eat healthier (Christophet et al., 2017).

Finally, most apps allow to monitor insulin intake, but none consider carbohydrate intake or blood glucose measurements. Yet, more fine-grained monitoring is essential to avoid medication errors: by tracking nutrient intake during the day, T2DM patients can better determine the required insulin dose, thus avoiding hyper- or hypoglycaemia. Insulin dose calculators can further avoid medication errors by indicating the number of required insulin units.

Studies have shown that apps designed to monitor physical activity can benefit diabetic patients too (Kordonouri & Riddell, 2019). We therefore recommend that app developers implement calorie counting as this is useful for determining optimal nutrient intake (Scarry et al., 2022).

4.1.2 Integration of Technology into Self-Care

The most common measurement inputs were blood pressure, body weight, and HbA1c. In a similar study, researchers found that smartphone apps focused primarily on monitoring body weight, blood glucose, HbA1c, and the units and types of insulin used (Ersotelos et al., 2018).

Although many apps' features are aimed at monitoring and controlling T2DM, they do not include tests for early detection of the risk of developing chronic complications such as neuropathy (Jamin et al., 2021), ocular retinopathy (Khura et al., 2021), and diabetic foot (Al-Rubeaan et al., 2015; Ploderer et al., 2018; Wang & Lo, 2018). Furthermore, none of the apps we analyzed monitored important indicators of complications (e.g., eye exams, foot exams, sensory testing). Early detection could reduce chronic diabetes complications and associated high costs (Chawla et al., 2020; Farshchi et al., 2014). We believe smartphone apps could help detect risks of developing complications more quickly, thus reducing costs and improving treatment outcomes and patients' quality of life. Therefore, we recommend that app developers include estimated risks of complication onset, thus contributing to early screening and preventing health deterioration.

4.1.3 Role of the Diabetes Care and Education Specialist

Our results represent a higher number of self-care behavior functions regarding *problem solving*, *risk reduction*, and *healthy coping*. We speculate that smartphone apps in the past were more focused on T2DM and were not patient-oriented because patient-centered care is still an evolving concept (Fix et al., 2018; Santana et al., 2018). Therefore, app designers have not yet integrated it into the mobile environment to such an extent. Patient-centered smartphone apps would place more emphasis on improving patient health and well-being and preventing complications rather than diagnosis. Nevertheless, there is still a lack of risk prevention regarding T2DM. Smartphone apps could provide tips for a healthy lifestyle, such as taking care of proper oral hygiene, avoiding cigarette smoke, etc. There is evidence that smartphone apps can effectively influence lifestyle changes in T2DM (Wu et al., 2019).

4.2 Improving the Overall Quality of Apps

Unfortunately, the overall quality of smartphone apps in our sample is rather average. We propose several recommendations about aesthetics, information amount, and engagement to improve apps' quality.

First, it is concerning that apps generally scored low in terms of aesthetics, because apps' likeability depends on their visual design (Trapp & Wienrich, 2018). One potential solution is to display information more visually, as this can increase motivation for self-management (McMillan et al., 2017). In this regard, *forDiabetes: diabetes self-management app* is a great example: its layout is simple and clear, its graphics are of high quality, and its visuals are attractive and memorable.

Second, the quality and quantity of information provided in apps were deemed moderately relevant and comprehensive. To further improve this aspect, apps could inform patients with more evidence-based information on T2DM; for example, symptoms, risk factors, prevention, and coping strategies. This additional information could, for example, be provided as personalized advice or links to relevant health articles. In all cases, simple language should be used to ensure patients understand the contents, and information should be tailored to patients' needs and knowledge (Torbjørnsen et al., 2019).

Third, we found that apps were deemed rather interesting and useful for patients, facilitating adjusted settings. However, with an average score of 3.86 out of 5, there is still room for improvement. To make apps more engaging, we propose integrating motivational techniques into smartphone apps. For example, gamification can improve user engagement and motivation by incorporating game-design elements (e.g. leaderboards, badges, and points) into non-gaming contexts (King et al., 2013). We found that only the *Diabetesdagboka* app engages users to achieve self-chosen goals with gamification (e.g., rewarding regular exercise with trophies).

4.3 Smartphone Apps and the Future of m-Health

Finally, we want to take a step back and briefly discuss our research in the light of m-health.

Information and communication technology are increasingly being integrated into healthcare, requiring a higher health literacy and a more active role of patients (Kim & Xie, 2015; Santana et al., 2021). This shows the urgency of clearly providing the right amount of information to patients. Whereas the smartphone apps we reviewed target adults diagnosed with T2DM, children might require less complex apps. We believe this is particularly important as children too are an important target group for future m-health applications. For example, smartphone apps could help motivate young diabetic patients to efficiently monitor their physical activity, diet, and blood sugar (Majeed-Ariss et al., 2015; Paramanik et al., 2019).

In general, we believe m-health holds a lot of potential for monitoring lifestyle and improving self-care, which are both especially relevant in the context of T2DM. However, given our findings, we agree with researchers such as Veazie et al. (2018) that there is still much room for improving existing T2DM self-care smartphone apps, for example by supporting better collaboration between doctors, patients, and researchers. At the same time, as m-health is increasingly integrated into patients' daily lives, it is necessary to promote awareness of how smartphone apps can benefit self-care and what its potential risks are (Gong et al., 2020).

4.3 Limitations

Our study has several limitations. First, we assigned several self-care behavior functions to AAED7 categories ourselves, which hampers comparison with other work. At the same time, this contributes to the field, as we have identified some new functions. Second, although we relied on clear definitions for the different self-care behavior functions and involved two graduate nurses in our study, assessing apps remains subjective. Other health experts may assess apps differently. Third, we restricted our review to free smartphone apps that do not require a username or login for regular operation. Doing so, we may have missed interesting apps. Fourth, we only included smartphone apps for iOS and Android, the most prominent smartphone operating systems (Götz et al., 2017). Fifth, we carried out our review in 2021, so we allow for the possibility that new apps for diabetes self-management have been developed since then.

5 Conclusion

Although m-health for maintaining T2DM is actively being developed, our systematic analysis shows that the wide range of available smartphone apps still has shortcomings. Addressing these according to our observations and recommendations would help patients to manage their condition better and reduce complications. In sum, we encourage app developers to pay more attention to educating users about the dangers of life-threatening and chronic complications. Furthermore, to motivate patients to monitor their condition closely and adopt a healthy lifestyle, we also see an opportunity for integrating motivational techniques and visual data representations in apps. In this way, we believe that smartphone apps can contribute to improving patients' health and preventing health deterioration.

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