Influence of Patient Characteristics and Psychological Needs on Diabetes Mobile App Usability in Adults with Type 1 or Type 2 Diabetes on Insulin Therapy

Helen NC Fu, PhD, School of Nursing, University of Minnesota
Terrence J Adam, PhD, MD, Institute for Health Informatics, University of Minnesota
Joseph Konstan, PhD, Department of Computer Science and Engineering, University of Minnesota
Julian Wolfson, PhD, School of Public Health, University of Minnesota
Thomas R Clancy, PhD, School of Nursing, University of Minnesota
Jean F Wyman, PhD, School of Nursing, University of Minnesota

Helen Fu, School of Nursing, University of Minnesota
5-140 Weaver-Densford Hall, 308 Harvard Street SE, Minneapolis MN 55455
Tel: 612-624-2132, Fax: 612-625-7180, Email: helen007@umn.edu
Abstract

**Background:** Despite more than 1,100 diabetes mobile applications (apps) are available, few apps are used widely related to limited usability or application of a behavior theory in app design.

**Objective:** Guided by Self-Determination Theory, this study assessed the usability of diabetes apps and whether usability was associated with patient characteristics and psychological needs for competence, autonomy, and connectivity important for health behavior motivation.

**Methods:** Using a crossover randomized design, 92 adults with type 1 or 2 diabetes tested two Android apps (*mySugr* and *OnTrack*) for tasks including data entry, blood glucose (BG) reporting, and data sharing. Multivariable linear regression models examined associations between patient characteristics, psychological needs, user satisfaction and performance (task time, success, and accuracy).

**Results:** Higher user satisfaction was observed for patients with less education and for those reporting more competence, autonomy, or connectivity with a healthcare provider (*P* < .05). User performance was associated with age, sex, education, and diabetes duration. Older patients required more time and had less successful task completion. Men needed more time and technical support than women. A high school education or less and a diabetes duration of 10+ years were associated with lower task accuracy (*P* < .01).

**Conclusions:** Diabetes app usability was associated with psychological needs that are important for motivation. To enhance patient motivation to use diabetes apps for self-management, clinicians should address competence, autonomy, and connectivity by teaching BG pattern recognition and lifestyle planning, customizing BG targets, and reviewing home-monitored data.
via email. Older male users and those with less education and greater diabetes duration may benefit from patient-centered app training and ongoing technical support.
Introduction

Background

Patients with diabetes may benefit from self-management interventions to prevent complications including stroke and vision loss. Poor diabetes management correlated with 2.3 times higher health care expenditures compared to those without diabetes [1]. Adhering to medical nutritional therapy and choosing what to eat are challenging for many patients with diabetes [2]. Using a diabetes app to record diet and track blood glucose (BG) shows promise to increase diet and medication adherence [3]. Small trials showed that using a diabetes app can improve glycemic control with a 0.4%–1.9% reduction in hemoglobin A1c (HbA1c) levels [4–6], but few patients use apps, possibly due to design problems and limited usability [7].

Diabetes app usability is the degree to which a user (patient) feels satisfied and finds the experience to be efficient and effective to accomplish tasks such as tracking BG readings [9]. Patient characteristics influence user experience, but few studies have examined the effect of age and sex on app usability [10–12]. Patients aged 56 years and older reported lower user satisfaction [13], and women made more errors than men when entering BG readings [11]. Technology experience and confidence also influenced patient ability to use diabetes apps. Glucose Buddy and MyFitnessPal did not match patient knowledge and ability, and patients reported that app designs were too complicated [14]. Most apps provide information input and output only [8], and prior usability studies did not consider health behavior theories. Assessing app usability and its relationship with patient characteristics and health behavior theoretical constructs will fill critical knowledge gaps in user-centered design and best practices to promote diabetes self-management.

Theoretical Framework
The Self-Determination Theory (SDT) by Deci and Ryan (2000) was used to understand patient perspectives on app usability and how motivation in diabetes care plays a role in app use. The motivation for healthy behavior is promoted when patients experience satisfaction in three psychological needs: competence, autonomy, and relatedness [15]. Intrinsic motivation occurs when patients endorse personal benefits of healthy behaviors [16]; endorsement of a diabetes app can then motivate patients to use apps. Individual background characteristics play a role in psychological needs and product needs that subsequently contribute to user-centered design and app use (Figure 1). Competence need is the patient’s desire to confidently control their BG in the target range [17]. Apps can increase competence by displaying an out-of-range BG readings report to increase patient understanding of BG numbers. Autonomy need is a patient’s desire for empowerment in having options to change behaviors [16]. Apps can increase autonomy by providing BG reports and carbohydrate (carb) intake patterns for all meals. Patients can visualize which meals require better carb control and health behavior changes in diet, insulin dose, or activity level. Relatedness or connectivity need is a patient’s desire to be cared for [18]. Patients are more likely to adopt behaviors when they feel supported and connected with people they trust such as a healthcare provider [16]. Apps help patients connect with healthcare providers by supporting email communication and sharing home-monitored data.

**Objectives**

This study’s goals were to test two top-rated diabetes apps and to examine the association between patient characteristics, psychological needs, and app usability. Aim 1 was to determine the relationships between patient characteristics (e.g., age, sex, education, technology use, diabetes history, and motivation) and app usability. We hypothesized that patient characteristics will predict user satisfaction and user performance in task time, success, and accuracy. Aim 2
was to determine the relationship between psychological needs important for motivation and app usability. We hypothesized that user satisfaction will be associated with psychological needs for competence, autonomy, and healthcare provider connectivity—theoretical constructs from Self-Determination Theory on motivation.

Methods

Study Design

A randomized crossover design was used to test two Android apps (*OnTrack* and *mySugr*) listed as “the Best Diabetes Apps 2016” by *Healthline*. The Android platform was selected because it has the greatest number of users (52.7%) [19]. Since age is a potential confounder in usability testing [20], we created two age-based strata: adults age ≥ 56 years and adults < 56 years. Using a computer software program, a statistician randomly assigned an app testing order of AB or BA within each age stratum sealed in an opaque envelope blinded the principal investigator (PI). The primary usability outcome was user satisfaction measured by the System Usability Scale (SUS) [21]. Secondary outcomes assessed user performance including efficiency (task time) and effectiveness (task success and accuracy). The University of Minnesota Institutional Review Board approved the study. All participants signed an informed consent document and received a $50 honorarium.

Participants

From July 26, 2017, to November 30, 2017, we conducted in-person app testing with participants who responded to flyers posted at community or veteran clinics, support groups, universities, community bulletins, and online postings on Craigslist and Facebook. A total of 92 participants met all inclusion criteria: (1) age 18 or older, (2) type 1 or 2 diabetes, (3) insulin
therapy for at least 6 months, (4) Android smartphone use for at least 6 months, (5) English proficiency, (6) adequate vision to read email or text messages on their current smartphone, and (7) smartphone use proficiency. Individuals who used any diabetes app in the past 6 months or had ever used OnTrack or mySugr were excluded.

**Procedures**

Individual study sessions were held in a private room. The sessions averaged 2 hours, ranging from 1 to 3.5 hours. During app training, participants watched YouTube videos posted by the app developers and practiced following a checklist for seven tasks on a Samsung 5S study phone: (1) enter a carb intake, (2) enter an exercise activity, (3) enter an insulin dose, (4) enter a BG reading, (5) locate a BG report for days of the week, (6) locate a BG report for each meal, and (7) email a BG report. During app testing, participants tested each app by following a checklist with a different task order and data units compared to app training. SUS questionnaire was completed at the end of each app test. During a 30-minute break between the first and second app test, participants completed the background survey and were given an opportunity to eat a light snack and use the restroom. App training and testing were conducted by the PI following a study protocol including a written standardized technical support. Another researcher checked fidelity from the audio recording of the study sessions. Field notes and app preference comments were recorded by the principal investigator.

**Measurements**

User satisfaction (primary outcome) was rated by the SUS, a 10-item questionnaire given immediately after each app test [21]. The SUS is widely used in product usability evaluation with a reliability coefficient α of 0.91 [20] and a loading factor > 0.3 for construct validity [22]. Scores > 70 are acceptable; scores ≥ 85 are excellent. Scores between 50 and 69 are marginally
acceptable; scores ≤ 50 are unacceptable [23]. Secondary outcomes were user performance in terms of efficiency measured by task time and effectiveness measured by task success and accuracy. Task time is the total task completion time per app. Task success is the degree to which a user independently completed required tasks [24]. Each app task success was rated from 0% to 100%. The rating is zero when the app lacked a testing function or when a participant received more than 50% of standard technical support. The user success rate was calculated by averaging success of all tasks. The user accuracy was whether the participant performed tasks correctly (e.g., correct insulin dose), calculated by averaging accuracy of all tested tasks.

Patient characteristics were self-reported in a background survey of 32 items that included demographics (age, sex, race/ethnicity, and education), smartphone brand, technology use, diabetes factors (types, HbA1c, duration, insulin use, BG testing, and prescribed BG testing), plus an established motivation scale, the Treatment Self-Regulation Questionnaire (TSRQ), assessing patients’ reasons for engaging in diabetes self-management behaviors with 8 items for intrinsic motivation and 11 items for extrinsic motivation rated on a seven-point Likert scale [17]. Both types of motivation scores were calculated by averaging the response ratings, which ranged from 1 (not true at all) to 7 (very true). Overall motivation was assessed by the Relative Autonomy Index (RAI), calculated by subtracting the intrinsic motivation score with the extrinsic motivation score. Positive scores indicate greater intrinsic motivation, whereas negative scores indicate greater extrinsic motivation. TSRQ has been validated across settings and for other health behaviors with an internal consistency α coefficient > 0.73 in a prior study [25] and 0.82 in this study.

Competence in diabetes self-management was measured by the Perceived Competence Scale (PCS), which ranged from 1 (not true at all) to 7 (very true) on a 7-point Likert scale with
four items and scored by averaging the responses [26]. Its internal consistency $\alpha$ coefficient was > 0.80 in a prior study [17] and 0.88 in this study. Interest in learning diabetes management is a subcomponent of autonomy [27]. Autonomy in diabetes management was measured by four items designed by the investigator and validated with expert testing that estimated patient interest in identifying personal BG readings and carb intake trends. Responses are on a 5-point Likert scale rating from 1 (strongly disagree) to 5 (strongly agree) and scored by averaging the responses. Its $\alpha$ coefficient of 0.74 was acceptable. Healthcare provider connectivity was rated by the Health Care Climate Questionnaire (HCCQ), assessing the degree to which primary healthcare providers offer autonomous support in diabetes management [28]. The score is based on an average response to six items on a 7-point Likert scale rating from 1 (strongly disagree) to 7 (strongly agree). Its reliability $\alpha$ coefficient was 0.82 in a prior study [28] and 0.94 in this study.

**Statistical Analysis**

The sample size ($n = 84$) for a regression model was based on 13 predictors, $R^2$ correlation of 0.2, $\alpha$ of 0.05, and 10% attrition resulting in a target sample size of 92. The only missing data was a HbA1c level from one participant. Residual plots showed no evidence of heteroskedasticity. Analyses of $t$ and Chi-square tests were used to assess differences between two age strata and sex groups. Paired $t$ tests of mySugr and OnTrack usability scores showed significant differences ($P < 0.05$), hence all regression analyses were adjusted for app group and testing order with an interaction term. Statistical significance was set at an $\alpha$ of 0.05 except where Bonferroni corrections were used to adjust for multiple comparisons. All analyses were performed using R statistical software [29].
For Aim 1, a linear mixed effect multiple regression model of Analysis of variance (ANOVA) analyzed both random effect (repeated app testing) and fixed effect (app group). The full model was run separately for each usability outcome model, including 15 predictors of patient characteristics, with smartphone brand and education collapsed into dichotomous variables (Samsung vs not and having high school education or less vs having education higher than high school). For Aim 2, the model for Aim 1 was used by adding a psychological need predictor (e.g., competence) while adjusting for patient characteristics covariates (key demographics, technology factors, diabetes history, and motivation), testing order, app group, and an interaction term between testing order and app group. We also assessed the individual mediation effect of task time, success, and accuracy on user satisfaction to explain all or part of the relationship between the psychological need and user satisfaction [30].

Results

Sample Recruitment and Characteristics

Diverse recruitment sites yielded 92 participants who completed the study from urban and suburban Minnesota: 46 were recruited from Facebook (50%), eight from patient referrals (9%), seven from a community clinic (8%), six from a university (6.5%), six from public housing (6.5%), five from Craigslist (5%), four from a veteran clinic (4%), three from diabetes support groups (3%), and seven from miscellaneous sites (8%). Participant characteristics are presented in Table 1. More than half of participants were women, nearly half used Samsung phones, and 70% had type 2 diabetes. The mean age was 54 years (range 19–79) with median age of 57, and the mean HbA1c was 8.2% (range 5–14) or 66 mmol/mol (range 31–130).
App Usability

Participants rated the two apps as marginally acceptable (SUS scores between 50 and 69) as shown in Table 2. OnTrack received an SUS score of 68 that is considered a “D” grade (e.g., scores between 60 and 69). Meanwhile, mySugr received a SUS score of 55 that is an “F” grade (e.g., scores less than 60). User performance was better for OnTrack compared to mySugr: more efficient (6.6 vs. 7.5 minutes for task total time, \( P < .001 \)), more effective (84% vs. 80% task success, \( P = .03 \)), and more accurate (74% vs. 63% task accuracy, \( P < .001 \)).

Patient Characteristics

Demographics, technology use, diabetes factors, and motivation did not predict user satisfaction assessed by the SUS for tested apps (Table 3). Age, sex, and education did predict user performance in task time and success rate. Adults over age 56 years took an extra 2.2 minutes [95% CI 1.1–3.2] for task time, had lower task success rate [95% CI 3.5–14.3%], and higher task error rate [95% CI 4.2–16.4%] compared with adults age 18–55 years. On average, for every 10 years of age, adult patients spent 0.8 minutes longer to use app (\( P < .05 \)), and the task success rate decreased by 4.6% (\( P < .01 \)). Men were less proficient, took extra 1.7 minutes (\( P < .05 \)) and achieved 6.9% less success (\( P < .05 \)) compared to women. Participants with education beyond high school had 6.4% less user satisfaction (\( P < .05 \)) and greater success by 10.5% compared to those who did not (\( P = .003 \)). Current Samsung smartphone users were 7.3% more accurate (\( P = .054 \)).

Neither type 1 or 2 diabetes predicted task time or success, but diabetes duration had a negative effect on user accuracy (\( P = .023 \)). The longer duration of diabetes, the less accurate participants were in using diabetes apps. A 10-year increase in diabetes duration was associated with an 8.5% drop in task accuracy, whereas the duration of insulin use was associated with a
7.1% increase in accuracy ($P = .058$). Glycemic control of HbA1c level showed no association with user satisfaction and performance. Self-reported BG testing frequency, prescribed BG testing frequency, and motivation for diabetes care were not associated with app usability.

**Psychological Needs**

Psychological needs were significantly associated with user satisfaction ($P < .05$) but not associated with user performance. This supports our study hypothesis that patient ratings of competence, autonomy, and healthcare provider connectivity are related to user satisfaction in diabetes apps. Patients who rated competence in their diabetes care were satisfied with diabetes apps: A one-unit increase in diabetes competence score was associated with an increase of the SUS score by 3.1 points ($P < .05$) (Table 4). Similarly, patients who reported greater autonomy and interest in learning their personal BG and carb patterns were more satisfied with the apps ($P < .01$): A one-unit increase in the autonomy score was associated with an increase of the SUS score by 5.9 points ($P < .01$). Patients who rated a higher connectivity with healthcare providers expressed higher user satisfaction: A one-unit increase of connectivity score was associated with increased SUS score of 2.5 points ($P < .05$). The association between user satisfaction and psychological needs was mediated by task time, success, and accuracy in a small proportion (0.5%–19.7%), which was not statistically significant.

**Discussion**

**Psychological Needs and User Satisfaction**

To our knowledge, this is the first study to report a relationship between app usability and the characteristics and psychological needs of the patient. A strength of our approach was the relatively large and diverse study population ($n = 92$) for usability testing, because most mHealth
usability evaluations have fewer than 30 participants and limited recruitment sites. Our study population was mixed urban and suburban and included African Americans and Native Americans. Our findings indicate that psychological needs and education are important factors in app usability, whereas patient characteristics are important for user performance or the ability to use an app efficiently, successfully, and accurately.

Diabetes app usability, as assessed by user satisfaction (SUS), was not associated with age, sex, diabetes profiles, technology factors, or motivation. Psychological needs were associated with user satisfaction. Competence in diabetes care associated with greater user satisfaction. In our study, patients wanted to use the app to increase their competence and preferred the convenience to track data on the go. A middle-aged patient said, “this would work for me since I always have my phone.” Apps offering an analysis report make it “easy to see the BG was out of range,” according to another patient. These findings agree with prior research that patients liked educational information and goal setting in apps to help them plan self-management activities [14].

Autonomy in diabetes care, as assessed by patient interest in personal patterns, correlated with greater user satisfaction and is consistent with prior research that diabetes app can help patients set realistic goals and see choices to modify behavior [14]. Patients want a customized care plan within an app to help them control diabetes and learn to improve eating habits [31]. According to one 62-year-old patient, the app can show “the last three months … how food influenced my BG, eating habits, and time frame in the schedule fluctuation.”

Addressing patient desire or need to connect with a healthcare provider is important for patient engagement in a mHealth intervention. Well-connected patients who received autonomous support from their healthcare provider rated higher satisfaction with diabetes apps.
Patients were more motivated to engage in diabetes care and use mHealth tools when they perceived their healthcare providers to be autonomous supportive [32]. Apps facilitate data sharing and patient–provider communication. One 58-year-old patient indicated: “[I do] not rely on my memory to tell my doc how I [am] doing, … I can just show her my phone.” Clinicians can view data trends and patterns in analysis reports emailed to them or view them on patients’ smartphones during clinic visits; real-time data facilitate discussions with patients and pinpoint exact areas for behavior changes.

**Patient Characteristics and User Performance**

Patient characteristics correlated with a patient’s ability to use an app. User performance in task time, success, and accuracy varied by age, sex, education, or diabetes duration when controlled for covariates (e.g., education, diabetes types, HbA1c, BG testing, and motivation). A10-year age increment was associated with slower time performance of 0.8 minutes and lower success performance by 4.6%; surprisingly, age did not correlate with accuracy performance since younger users are typically more accurate with technology use. This may be explained by the design of this study, which provided as much technical support and time as desired. In contrast to prior studies, women outperformed men in time efficiency and task success. This result held when accounting for other participant factors, possibly because women spend more time on smartphones and apps than do men. One study tracked 75,000 people using the most popular websites and apps found that women spend more time than men on smartphones (49% vs. 39%) [33]. Women also use social media apps (e.g., Facebook) more often than men (83% vs. 75%) [34]. We ran a separate full model adjusted for Facebook recruitment, which did not affect results. Education beyond high school correlated with user success performance only, meaning
that if participants with high school education or less are provided with technical support, they can learn to use an app as efficiently and accurately as those with more education.

Diabetes duration was significantly related to user accuracy: A 10-year diabetes history decreased accuracy by 8.5%, perhaps because of diabetes complications. Diabetes peripheral neuropathy rate increases by twofold for those with diabetes for longer than 10 years [35]. Diabetes retinopathy prevalence at 10 years diabetes duration is 60% [36]. Finger nerve pain can make it hard and painful to tap correct app icons. Icons and prints on a small smartphone screen could be hard to read for those with vision complications. In this study, most participants had suboptimal controlled diabetes with elevated mean HbA1c level of 8.2% (66 mmol/mol) since a target HbA1c level for adults older than age 65 years is < 7.5% (58 mmol/mol) [37] and ≤ 7% (53 mmol/mol) for adults under age 65 without a history of hypoglycemia [2]. HbA1c level, BG monitoring frequency, and motivation in diabetes care did not correlate with app usability.

**Clinical Implications**

Our study provides new insights into the theoretical basis of health behavior in app usability. Application of the Self-Determination Theory in app design proved to be important for bridging the gap between patient needs and the technology experience. Psychological needs of competence, autonomy, and connectivity with a healthcare provider (motivational constructs) were associated with user satisfaction. These findings suggest that clinicians should address these psychological needs when recommending the use of a diabetes app. Clinicians could address competence by providing education on BG and carb pattern recognition and planning for lifestyle modifications (e.g., lowering carb intake). Clinicians could customize a care plan and a BG target range to address autonomy so that patients can set up a parameter in their apps to analyze BG accordingly. Clinicians could offer autonomous support and receive home-monitored
data by email to promote connectivity, which can lead to long-term app use. Clinicians should screen for diabetes complications that may affect user accuracy.

**Limitations and Future Directions**

Several limitations in this study provide directions for future research. Two diabetes apps were tested in a single study session with findings applicable for a short-term app experience. User satisfaction may change with long-term app use. Future research should include long-term follow-up, record app adherence rate, and assess factors affecting whether or not long-term app use will be sustained. Different proportions of non-White participants were recruited through sites such as public housing and a federal qualified health center. This heterogeneity in race breakdown by recruitment site made it challenging to distinguish between race effect and recruitment effect, and race/ethnicity was not a covariate in the final model.

Unmeasured covariates, such as socioeconomic status (e.g., income), types of medical insurance, diabetes complications, and obesity could influence results. However, our study included multiple recruitment sites and a variety of patient backgrounds with different education levels, insulin use types (pump users on private insurance and those on injection therapy on public insurance program), and different housing facilities. Covariates, such as education and smartphone model, may count as a proxy for socioeconomic status. A multiple variable model accounted for common demographics and diabetes history. Our study excluded adolescents with diabetes as well as family caregivers. Future studies should recruit minority patients, adolescents, and caregivers. We did not include laboratory-based usability measures. Future studies can further identify app use barriers through other methods of quantifying usability problems (e.g., recording screen reaction, counting keystrokes, and tracking eye movements).
Conclusions

Application of the Self-Determination Theory in diabetes app usability revealed that addressing psychological needs for diabetes care competence, autonomy, and connectivity with a health care provider may enhance patient motivation to use diabetes apps. Patient-centered training and ongoing technical support could improve usability for older male users and those with less education and greater diabetes duration. Voice-over commands and wireless data uploads would improve accuracy by eliminating manual data entry. App vendors could better support data sharing and aggregation (e.g., importing BG reports into the medical record), making reports accessible to clinicians. User-centered apps are desired by patients; app designs and features should match appropriate user age and ability.

Acknowledgments

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Conflict of Interest

None declared.
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metric/

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the theoretical structure of the Treatment Self-Regulation Questionnaire (TSRQ) across


Figure 1. Usability model of diabetes app use.
Table 1. Sample characteristics and psychological needs.

<table>
<thead>
<tr>
<th>Characteristics/ psychological needs</th>
<th>(n = 92)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years (SD)</td>
<td>54 (13)</td>
</tr>
<tr>
<td>Men, n (%)</td>
<td>38 (41)</td>
</tr>
<tr>
<td>Race, n (%)</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>57 (62)</td>
</tr>
<tr>
<td>Black/African American</td>
<td>23 (25)</td>
</tr>
<tr>
<td>Native American</td>
<td>10 (11)</td>
</tr>
<tr>
<td>Asians</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Highest completed education, n (%)</td>
<td></td>
</tr>
<tr>
<td>Elementary</td>
<td>4 (4)</td>
</tr>
<tr>
<td>High school or equivalent</td>
<td>27 (29)</td>
</tr>
<tr>
<td>Community/technical school</td>
<td>31 (34)</td>
</tr>
<tr>
<td>Bachelor’s degree</td>
<td>19 (21)</td>
</tr>
<tr>
<td>Graduate degree</td>
<td>11 (12)</td>
</tr>
<tr>
<td>Device brand, n (%)</td>
<td></td>
</tr>
<tr>
<td>Samsung</td>
<td>44 (48)</td>
</tr>
<tr>
<td>LG</td>
<td>19 (20)</td>
</tr>
<tr>
<td>iPhone</td>
<td>8 (9)</td>
</tr>
<tr>
<td>ZTE</td>
<td>7 (8)</td>
</tr>
<tr>
<td>Motorola</td>
<td>6 (6)</td>
</tr>
<tr>
<td>Other</td>
<td>8 (9)</td>
</tr>
<tr>
<td>Smartphone comfort level, n (%)</td>
<td></td>
</tr>
<tr>
<td>Very uncomfortable</td>
<td>23 (25)</td>
</tr>
<tr>
<td>Neither</td>
<td>12 (13)</td>
</tr>
<tr>
<td>Comfortable</td>
<td>33 (36)</td>
</tr>
<tr>
<td>Very comfortable</td>
<td>24 (26)</td>
</tr>
<tr>
<td>Diabetes types, n (%)</td>
<td></td>
</tr>
<tr>
<td>Type 1</td>
<td>28 (30)</td>
</tr>
<tr>
<td>Type 2</td>
<td>64 (70)</td>
</tr>
<tr>
<td>HbA1c % (ranges 5–14)</td>
<td>8.2 (1.5)</td>
</tr>
<tr>
<td>Diabetes duration (years)</td>
<td>17 (11)</td>
</tr>
<tr>
<td>Insulin duration (years)</td>
<td>12 (12)</td>
</tr>
<tr>
<td>Insulin use types, n (%)</td>
<td></td>
</tr>
<tr>
<td>Insulin pump</td>
<td>14 (15)</td>
</tr>
<tr>
<td>Long- and short-acting injection</td>
<td>46 (50)</td>
</tr>
<tr>
<td>Long-acting injection</td>
<td>28 (30)</td>
</tr>
<tr>
<td>Short-acting injection</td>
<td>2 (2)</td>
</tr>
<tr>
<td>None (stopped use)</td>
<td>2 (2)</td>
</tr>
<tr>
<td>BG testing prescribed per day</td>
<td>3.8 (1.8)</td>
</tr>
<tr>
<td>BG testing per day</td>
<td>6.2 (1.4)</td>
</tr>
<tr>
<td>Daily or less, n (%)</td>
<td>19 (21)</td>
</tr>
<tr>
<td>2 times a day, n (%)</td>
<td>34 (37)</td>
</tr>
<tr>
<td>4 times a day, n (%)</td>
<td>21 (23)</td>
</tr>
<tr>
<td>&gt; 4 times a day, n (%)</td>
<td>18 (19)</td>
</tr>
<tr>
<td>Overall motivation</td>
<td>2.16 (1.3)</td>
</tr>
<tr>
<td>Intrinsic motivation</td>
<td>5.43 (0.9)</td>
</tr>
<tr>
<td>Extrinsic motivation</td>
<td>3.26 (1.2)</td>
</tr>
<tr>
<td>Competence</td>
<td>5.38 (1.1)</td>
</tr>
<tr>
<td>Autonomy</td>
<td>3.92 (0.6)</td>
</tr>
<tr>
<td>Connectivity with healthcare provider</td>
<td>6.05 (1.2)</td>
</tr>
</tbody>
</table>
Data are mean (SD) unless otherwise indicated. Abbreviation: BG, blood glucose and HbA₁c, hemoglobin a1c.  

a 66 mmol/mol,  

b Also known as the self-determination index obtained from intrinsic motivation score minus extrinsic motivation score.
<table>
<thead>
<tr>
<th>Usability</th>
<th>Overall (N = 184)</th>
<th>mySugr (n = 92)</th>
<th>OnTrack (n = 92)</th>
<th>d [95%CI] (n = 92)</th>
<th>P&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Practice time, minutes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>19 (8)</td>
<td>22 (9)</td>
<td>16 (6)</td>
<td>5.6 [4.0, 7.2]</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Median (IQR)</td>
<td>17 (9)</td>
<td>20 (8)</td>
<td>14 (8)</td>
<td>5 (7)</td>
<td></td>
</tr>
<tr>
<td><strong>Satisfaction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>62 (18)</td>
<td>55 (18)</td>
<td>68 (15)</td>
<td>12.7 [8.2, 17.2]</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Median (IQR)</td>
<td>65 (23)</td>
<td>56 (25)</td>
<td>70 (15)</td>
<td>-15 (25)</td>
<td></td>
</tr>
<tr>
<td><strong>Efficiency, minutes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>7.0 (3.8)</td>
<td>7.5 (3.8)</td>
<td>6.6 (3.7)</td>
<td>0.8 [0.3, 1.3]</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Median (IQR)</td>
<td>6.0 (4.5)</td>
<td>6.4 (4.5)</td>
<td>5.6 (4.0)</td>
<td>0.7 (2.3)</td>
<td></td>
</tr>
<tr>
<td><strong>Success, %</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>82 (19)</td>
<td>80 (20)</td>
<td>84 (18)</td>
<td>-3.9 [0.3, 7.5]</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Median (IQR)</td>
<td>92 (33)</td>
<td>83 (33)</td>
<td>92 (25)</td>
<td>0 (16.7)</td>
<td></td>
</tr>
<tr>
<td><strong>Accuracy, %</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>68 ± 21</td>
<td>63 (22)</td>
<td>74 ± 20</td>
<td>-11.0 [6.0, 16]</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Median (IQR)</td>
<td>67 (33)</td>
<td>67 (33)</td>
<td>67 (17)</td>
<td>-16.6 (33.3)</td>
<td></td>
</tr>
</tbody>
</table>

N = 184 observations from randomized 92 patients who tested two apps in randomized order

<sup>a</sup> Obtained from paired t test comparing two apps, *mySugr* and *OnTrack*.  

---

Table 2. Diabetes app usability outcomes.
Table 3. Adjusted associations between patient characteristics and app usability.

<table>
<thead>
<tr>
<th>Predictors</th>
<th>Satisfaction (SUS)</th>
<th>Efficiency (min)</th>
<th>Success (%)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristics, effect (P)</strong></td>
<td>Model 1</td>
<td>Model 2</td>
<td>Model 3</td>
<td>Model 4</td>
</tr>
<tr>
<td>Age per 10 years</td>
<td>−0.5</td>
<td>0.8*</td>
<td>−4.6**</td>
<td>−2.5</td>
</tr>
<tr>
<td>Men vs. women</td>
<td>0.1</td>
<td>1.7*</td>
<td>−6.9*</td>
<td>−0.1</td>
</tr>
<tr>
<td>ᵃ HS vs. ≤ HS</td>
<td>−6.4*</td>
<td>−1.2</td>
<td>10.5**</td>
<td>0.3</td>
</tr>
<tr>
<td>Samsung vs. not Samsung</td>
<td>1.5</td>
<td>−0.8</td>
<td>5.3</td>
<td>7.3</td>
</tr>
<tr>
<td>Smartphone comfort</td>
<td>0.6</td>
<td>−0.1</td>
<td>0.6</td>
<td>−0.3</td>
</tr>
<tr>
<td>Diabetes type 2 vs. type 1</td>
<td>−5.5</td>
<td>1.6</td>
<td>−4.7</td>
<td>−7.4</td>
</tr>
<tr>
<td>Diabetes duration per 10-year</td>
<td>3.6</td>
<td>0.5</td>
<td>−0.1</td>
<td>−8.5*</td>
</tr>
<tr>
<td>Insulin duration per 10-year</td>
<td>−1.3</td>
<td>0.6</td>
<td>−3.1</td>
<td>7.1</td>
</tr>
<tr>
<td>HbA1c</td>
<td>0.4</td>
<td>−0.2</td>
<td>1.8</td>
<td>0.7</td>
</tr>
<tr>
<td>BG testing per day</td>
<td>−0.4</td>
<td>0.2</td>
<td>−1.7</td>
<td>−1.0</td>
</tr>
<tr>
<td>BG testing prescribed per day</td>
<td>−0.2</td>
<td>−0.2</td>
<td>0.9</td>
<td>−1.2</td>
</tr>
<tr>
<td>Motivation (TRSQ)</td>
<td>−0.4</td>
<td>−0.03</td>
<td>0.7</td>
<td>−0.1</td>
</tr>
<tr>
<td>Testing order</td>
<td>−3.9</td>
<td>−1.2</td>
<td>11.2**</td>
<td>3.6</td>
</tr>
<tr>
<td>App group</td>
<td>8.4*</td>
<td>−1.3**</td>
<td>9.8**</td>
<td>11.1*</td>
</tr>
<tr>
<td>Interaction order and app</td>
<td>8.3</td>
<td>0.9</td>
<td>−11.3</td>
<td>−0.5</td>
</tr>
<tr>
<td>Adjustedᵇ R²</td>
<td>0.14</td>
<td>0.35</td>
<td>0.31</td>
<td>0.17</td>
</tr>
</tbody>
</table>

N = 184 observations from randomized 92 patients. No significant P met the cutoff of 0.0008333 with Bonferroni multiple comparison.

ᵃ Completed highest education greater than high school compared with those who’s highest completed education was high school or less, those who did not.

ᵇ Obtained from linear regression model analysis without repeated measures.

*P < 0.05
**P < 0.01
Table 4. Adjusted associations between psychological needs and app usability.

<table>
<thead>
<tr>
<th>Psychological Need</th>
<th>Satisfaction (SUS)</th>
<th>Efficiency (min)</th>
<th>Success (%)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Competence</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted effect ($P$)</td>
<td>Model 1A</td>
<td>Model 2A</td>
<td>Model 3A</td>
<td>Model 4A</td>
</tr>
<tr>
<td>3.1$^*$</td>
<td>0.2</td>
<td>−0.1</td>
<td>−2.9</td>
<td></td>
</tr>
<tr>
<td>Adjusted$^a R^2$</td>
<td>0.16</td>
<td>0.35</td>
<td>0.31</td>
<td>0.18</td>
</tr>
<tr>
<td><strong>Autonomy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted effect ($P$)</td>
<td>Model 1B</td>
<td>Model 2B</td>
<td>Model 3B</td>
<td>Model 4B</td>
</tr>
<tr>
<td>5.9$^{**}$</td>
<td>−0.8</td>
<td>4.9$^*$</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Adjusted$^a R^2$</td>
<td>0.17</td>
<td>0.37</td>
<td>0.33</td>
<td>0.17</td>
</tr>
<tr>
<td><strong>Connectivity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted effect ($P$)</td>
<td>Model 1C</td>
<td>Model 2C</td>
<td>Model 3C</td>
<td>Model 4C</td>
</tr>
<tr>
<td>2.5$^*$</td>
<td>0.2</td>
<td>−0.02</td>
<td>−0.01</td>
<td></td>
</tr>
<tr>
<td>Adjusted$^a R^2$</td>
<td>0.16</td>
<td>0.35</td>
<td>0.31</td>
<td>0.17</td>
</tr>
</tbody>
</table>

$N = 184$ observations from randomized 92 patients, adjusted all models with 15 covariates listed in model 1 from Table 2, which included: age, sex, education, use of Samsung, smartphone comfort, diabetes types, diabetes duration, insulin duration, hemoglobin a1c, blood glucose testing per day, blood glucose testing prescribed per day, motivation, testing order, app group, and interaction term between order and app. No significant $P$ met the cutoff of 0.000781 with Bonferroni multiple comparison.

$^a$ Obtained from linear regression model analysis without repeated measures.

$^* P < 0.05$

$^{**} P < 0.01$