Mobile phone applications and type 1 diabetes: An approach to explore usability issues and the potential for enhanced self-management

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Article points

1. The epidemiological rise in diabetes prevalence is against a backdrop of an exponential increase in the personal use of mobile devices.
2. Applications ("apps"), which run on mobile devices, have potential benefits for people with diabetes, enabling sustained and more reliable tracking of personal trends in blood glucose levels.
3. This small-scale study examines the usability of four apps for diabetes care as well as a qualitative exploration of users' perceptions of a diabetes app.
4. Connecting with young people with diabetes and visualising personal data were important features of apps.

Key words

- Glucose-tracking
- Mobile applications
- Self-management
- Usability

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The global incidence of diabetes is increasing against an exponential backdrop of general use of personal mobile technologies. The progress in relation to data storage, wireless communications and mobile applications ("apps") has significant potential to support self-management strategies for people with diabetes. While there is an emergent evidence-base for positive benefits of these technologies within diabetes care, there are some current limitations, such as no agreed standards of what constitutes an appropriate app within the domain and more scope to improve the user-friendliness of apps for people with diabetes. This small-scale study used a mixed methodology approach to identify usability issues of current apps for diabetes care. The study also captures the individuals' experience of a glucose-tracking diabetes app, their motivation to use an app and the desirable features of an app. The outcomes suggest that the use of apps are appropriate for demographic groups such as children and young people, and the potential to visualise personal data via a glucose-tracking app is seen as an important feature by users.

The global incidence of diabetes is significantly increasing, and by 2025 this is predicted to reach 5 million in the UK (Diabetes UK, 2012a). This is a challenge for healthcare providers, and an important strategy is to facilitate self-management of people with diabetes in order to prevent short- and long-term complications. An example is the encouragement of tracking personal blood glucose trends in order to support appropriate treatment decision-making.

This epidemiological rise in diabetes prevalence is against a backdrop of an exponential increase in the personal use of mobile devices; more than 76 million mobile phones are owned by the UK public (Hitman, 2011). Personal mobile device use has potential benefits for people with diabetes; technological advances such as increased capacity for data storage, processing and Bluetooth or wireless connections can facilitate improved communication of data between glucose meters, mobile phones and other devices such as personal computers. This could enable sustained and more reliable tracking of personal trends in blood glucose levels.

There is a growing market for applications ("apps"); these run on mobile devices, such as a Smartphone, and can perform functions that would have previously been restricted to a personal computer. There is an increasing use of apps within healthcare (University of Cambridge and China Mobile, 2011); within diabetes care there are many examples that have been designed by, or with input from, individuals with diabetes, such as the "Diabetes UK iPhone Tracker App" (Diabetes UK, 2012b). These apps can generally be categorised into four areas:

- Glucose-tracking diaries.
- Carbohydrate estimation.
- Recipes.
- Diabetes education.

Page points

1. There is potential for mobile apps to have a role in the promotion of NICE guidelines (2011), which define the role of the healthcare professional in supporting optimal blood glucose control.
2. An intelligent mobile app would offer the individual timely feedback that is highly accurate and tailored to his or her blood glucose profile.
3. User-friendliness is important to whether a given technology can provide a practical benefit for individuals with type 1 diabetes who may be using their data to make personal insulin dose adjustments.
4. The aim of this research project was to undertake a small-scale study in order to uncover some common usability issues with glucose-tracking, diary-style apps developed for people with type 1 diabetes.

The evidence-base for mobile technologies to support self-management of diabetes

There is an emergent evidence-base of positive outcomes for people with diabetes through the provision of mobile technology to enhance normal clinic visits with communication and exchange of monitoring data with a healthcare professional (HCP); a small range of studies has demonstrated reductions in HbA_{1c} and an increased connection with self-care (Liang et al, 2010; Hussein et al, 2011; Lyles et al, 2011; Mulvaney et al, 2012).

There is potential for mobile apps to have a role in the promotion of NICE guidelines (2011), which define the role of the HCP in supporting optimal blood glucose control, taking into account "the experiences and preferences of the insulin users"; this is especially where the person with diabetes has a preference and affinity for the use of personal mobile technologies. It is therefore important for HCPs with a specialist interest in diabetes care to have an awareness of the technological development of apps; this includes the benefits and current limitations.

Current issues include the lack of a common consensus about what constitutes an appropriate mobile interface for a diabetes app. Additionally, available apps do not necessarily process data in an intelligent way (Curran et al, 2010); instead, the user has to enter the data and interpret the results. An intelligent mobile app would offer the individual timely feedback that is highly accurate and tailored to his or her blood glucose profile.

Usability

Usability is a concept that concerns the design of mobile apps. Computer software is intended to be highly "usable" (or user-friendly), which includes software that is quick and easy to use, without making mistakes and requiring little cognition or training to use. The discipline of human–computer interaction aims to produce computer technology with high usability, and it is underpinned by an ethos known as "user-centred design", which involves the end user in the design process.

User-friendliness is important to whether a given technology can provide a practical benefit for individuals with type 1 diabetes who may be using their data to make personal insulin dose adjustments. For example, some mobile devices have a small screen size, which makes data hard to visualise and requires manipulation by touchscreen; this is significant, given the association between diabetes, visual impairment and peripheral neuropathy.

Ciemans et al (2010) suggest that because most apps developed for diabetes care require manual input of data, this requires additional time and effort on the part of the user and offers little advantage over an electronic blood glucose monitor, which can upload data onto a computer. However, Lyles et al (2011) suggest that people with diabetes do not necessarily wish to feel confined to a computer to upload data. The research team philosophy is underpinned by the notion of personalised health care, and supports the latter perspective. This provides a rationale for improving usability issues related to diabetes care.

Study aims

The aim of this research project was to undertake a small-scale study in order to uncover some common usability issues with glucose-tracking, diary-style apps developed for people with type 1 diabetes. The authors also wanted to determine what would motivate individuals with type 1 diabetes to use an app as a component of self-management, and what features they would consider important within a mobile app. Crucially, this study also aimed to incorporate the user perspective by using a range of research methods.

Methodology

The goal was to take a snapshot of all the available iPhone glucose-tracking apps for diabetes management. In evaluating these apps, the authors were considering the functionality of the apps (what features are provided) as well as their usability (the user-friendliness). The available apps were filtered systematically with respect to their features, resulting in a selection of four apps (*Table 1*); these were then evaluated by individuals with diabetes regarding their functionality and usability (*Table 2*).

Study participants

The study gained ethical approval from the Oxford Brookes University's Research Ethics Committee. The authors recruited eight people with type 1 diabetes

who were members of local diabetes support networks, and included adults, young people and children (four adults and four people aged 8–16). Usability research (Faulkner, 2003) has demonstrated that a surprisingly large number of software usability problems can be uncovered with a relatively small sample size. In addition, the characteristics of the participants constituted a purposive sample for the collection of qualitative data.

Data collection methods

Quantitative approach

The participants were invited to a 1-hour session, which took place either on university premises or in their own home, where they were given a short tutorial and range of tasks to complete on an iPod Touch® (Apple Inc), which had been pre-loaded with the four selected apps:

- "Diabetes Diary".
- "Diabetes Personal Manager".
- "GluCoMo".
- "Rapid Calc".

Hand movements of the participants were videoed as they completed the tasks outlined in *Table 2*, in order to determine the nature and frequency of the errors made. In addition the participants were asked to complete a questionnaire to evaluate each app in terms of its effectiveness, efficiency, simplicity, users' satisfaction and cognitive load (*Table 3*). The videos were analysed by a human–computer interaction expert to determine the nature and the frequency of the errors made by the participants.

Qualitative methods

Participants were also offered the use of an iPod touch pre-loaded with the "Diabetes Diary" app, and asked to use this alongside their usual personal self-management strategy for a 1-week trial. This was followed up with a semi-structured interview, which aimed to gain overall experience on the usability of the app, motivation to use a mobile app to support diabetes self-management and identification of desirable features of an app. The interviews were audio-recorded, transcribed verbatim and then peer-reviewed by two members of the research team and an MSc Public Health research student. The data were analysed using grounded theory methods (Strauss and Corbin, 1990).

Table 1. Selection process to determine the apps to be assessed for usability.

Selection process for apps	Results (number of apps that fulfil criteria	Apps selected
● Identify all potentially relevant apps on iOS platform	232	
● Remove "light" or old versions of each app	222	
● Identify the primary operating functions and exclude all apps that do not offer this functionality	27	
● Construct tasks to test the key functionality using each of these methods:		
– Keystroke level modelling	8	
– Heuristics* e.g. minimalist design, ease of input	4	
		– "Diabetes Diary" – "Diabetes Personal Manager" – "GluCoMo" – "Rapid Calc"

*See Bellazi (2008).

Table 2. Tasks set to evaluate functionality of the four selected glucose-tracking apps.

Task	Description
1.	Set measurement units to mmol/L
2.	Log blood glucose level of 6.7 mmol/L
3.	Log carbohydrate intake of 50 g
4.	Log insulin dose of 5.5 units
5.	Display data graphically
6.	Export data via email or similar

Results

Quantitative analysis

Participants evaluated each of the four apps in terms of their effectiveness, efficiency, simplicity, users' satisfaction and cognitive load:

- *Effectiveness* – all of the set tasks were completed successfully, scoring 100%, apart from the Diabetes Diary app, which scored 83% for glucose and insulin logging. The conclusion is that all of the apps scored highly in this attribute, probably because of their simple functionality.

Table 3. Participant usability analysis – criteria used to assess each app.

Criteria	Analysis
Effectiveness	Whether users can successfully achieve their objectives was measured as the percentage of tasks solved
Efficiency	How much effort and resource is consumed in achieving the desired objectives was measured as the time taken to solve each task
Simplicity	The lack of obstruction in achieving objectives was calculated as the number of errors per task
Satisfaction	Whether the overall experience was satisfactory was calculated using the long-established System Usability Scale questionnaire (Brooke, 1996)
Cognitive load	Cognitive load was measured using the NASA-TLX Scale (Hart and Staveland, 1988; Hart, 2006), which is a subjective workload assessment tool and includes measurements for mental demands, physical demands, own performance and effort and frustration

Table 4. Mean data entry times for each of the four apps.

App	Glucose	Carbohydrates	Insulin	Total
Diabetes diary	1m 16s	18s	50s	2m 24s
Diabetes personal manager	40s	23s	19s	1m 22s
GluCoMo	51s	29s	15s	1m 35s
RapidCalc	36s	21s	32s	1m 29s

m=minutes; s=seconds.

Table 5. Mean number of errors for logging glucose, carbohydrate and insulin figures into each of the four apps tested.

App	Glucose	Carbohydrate	Insulin	Total
Diabetes Diary	1.92	0.33	1.83	4.08
Diabetes Personal Manager	1.08	1.75	0.50	3.33
GluCoMo	1.67	1.50	0.25	3.42
RapidCalc	1.50	0.33	0.75	2.58

- *Efficiency* – the time taken to solve each of the three data entry tasks (i.e. tasks 2–4 in *Table 2*) was measured for each app, and the mean times are given in *Table 4*. The most significant entry is the time taken to log glucose on the Diabetes Diary app, which takes considerably longer than on the other apps. This fits with the observed errors made by users; Diabetes Diary had a high number of touchscreen and affordance errors. There were also efficiency errors with the GluCoMo app, because the values for glucose, carbohydrate and insulin had to be entered on separate screens.
- *Simplicity* – the mean number of errors per task is given in *Table 5*, which shows that the Diabetes Diary app has the highest mean error rate and the RapidCalc app the least.
- *Satisfaction* – user satisfaction was assessed using the System Usability Scale (SUS; Brooke, 1996), a Likert scale giving a context-specific, subjective view of a system's usability. The authors found that there was less correlation between the SUS scores with either the efficiency or simplicity of the apps.
- *Cognitive load* – the mental demands placed on the user were measured using the NASA-TLX Scale (Hart and Staveland, 1988; Hart, 2006), a validated assessment tool for measuring mental, physical and temporal demands, as well as performance, effort and frustration. In general, for all four apps, users found that there were more mental demands placed on them than physical or temporal demands, and they ranked their performance as high. Users were also asked which data entry method they preferred – keyboard, slider or picker (*Table 6*).

Qualitative analysis

Participants used the Diabetes Diary for 1 week and answered the following questions (*Table 7*):

- What was the overall experience of using a mobile app for 1 week?
- What would motivate you to use a mobile app as a component of your diabetes self-management?
- What features would you like to see in the future development of mobile apps to support diabetes care?

Table 6. Preferred method of data entry.

Data entry method of app	% used
Slider	18
Picker	36
Keyboard	45

What was the overall experience of using a mobile app for 1 week?

Three overarching themes emerged after participants used the Diabetes Diary app for 1 week: accuracy, integration and intuition (*Table 7*):

- *Accuracy* – key concerns for all of the participants were the precision and accuracy of entering personal monitoring data. Frustration was expressed at various apps' inability to meet personal requirements; for example, overly

Table 7. Qualitative data analysis – participants' responses after trialling the Diabetes Diary app for 1 week.

Research questions	Core categories	Themes
What was the overall experience of using a mobile app for 1 week?	Accuracy	– Lack of calibration for personal insulin dose and blood glucose profile – Lack of clarity of data input requirements – Visual impairment and peripheral sensitivity
	Integration	– Duplication with data entered and stored in electronic blood glucose monitor – Potential to use with other platforms, e.g. "Cloud" technology – Synergy with technology used as part of personal lifestyle – Synergy with diabetes technologies, such as an insulin pump
	Intuition	– Appraisal of apps, sliders, pickers, compared with paper diary – Graphs to predict personal trends – Demographic drivers; children and young people
What would motivate you to use a mobile app as a component of your diabetes self-management?	Support for cognitive decision-making	Potential for: – Insulin dosage adjustment calculations – Alarms to prompt self-monitoring and frequency
	Potential to share data with a healthcare professional	– Timely feedback, support and advice – Access to expertise during acute episodes and emergencies
	Personal value attributed to mobile devices	– Technical personalities – Norms of youth
What features would you like to see in the future development of mobile apps to support diabetes care?	Safety-netting	Features to: – Correct data entry methods – Voice recognition for data entry – Injection site rotation guide – Enter data retrospectively – Insulin dose adjustment for personal requirements
	Feedback	– Correcting dose for carbs – Correcting dose for stress – Correcting dose for exercise – Alert to test for ketones – "Hypo" alert – Prediction of personal trends based on data stored – Efficient use and aggregation of stored data – Features to synchronise data in the "Cloud"

Page points

1. Sensory loss caused by peripheral neuropathy was seen as an issue concerning accurate data entry on a small touchscreen; visual impairment was also an issue.
2. The Diabetes Diary app was seen as a duplication of effort as most of the data entry features available did not exceed any features of personal electronic blood glucose monitors.
3. Some of the older adults within the study related differently to their experience of using the app, compared with the children and young people.
4. Young people and children appeared to more intuitively explore and appraise the methods of data entry and features, such as the opportunity to be able to visualise personal trends within a graph.

restrictive limits on ranges of numbers, such as for units of insulin and for blood glucose levels.

"You couldn't input high figures so the maximum number of millimoles that it would register would be 25. Now sometimes my readings are way above 25…" (43-year-old woman).

Sensory loss caused by peripheral neuropathy was seen as an issue concerning accurate data entry on a small touchscreen; visual impairment was also an issue.

"Because of my inability to see very well on the odd occasion, certainly if my blood sugars are particularly high and hence dexterity problems, I inadvertently inputted the wrong data so my finger would slip" (45-year-old woman).

- *Integration* – the Diabetes Diary app was seen as a duplication of effort as most of the data entry features available did not exceed any features of personal electronic blood glucose monitors.

"I think it's a great thing to have next to you. If it's the only thing that you ever use then, how can I say this, I didn't use it because I've got it all stored in my meter and so it's a second entry" (52-year-old man).

Conversely, participants acknowledged the use of technology in other areas of their personal lives and the management of their diabetes, and saw the potential for further app development to synergise with this.

"Besides the fact that, you know, children and young people like to play games and use computers and iPods and things, you know, these are things that they use all the time, it might encourage them a bit more to use it" (13-year-old boy).

- *Intuition* – some of the older adults within the study related differently to their experience of using the app, compared with the children and young people.

"… But for me it was a machine that I had to sort of do a favour to you to put the results in, which is fine, I didn't mind doing but it's not something I would do for myself…" (45-year-old woman).

Young people and children appeared to more intuitively explore and appraise the methods of data entry and features, such as the opportunity to be able to visualise personal trends within a graph.

"Very good app, I think by the end of it I'd changed my mind about how much I liked it […] It was a very useful way of being able to look at your blood sugars on the graph, seeing, you know, looking for patterns, watching out for things that could happen again" (16-year-old boy).

What would motivate you to use a mobile app as a component of your diabetes self-management?

The following overarching themes emerged in relation to the question about motivation to use a mobile app: support for cognitive decision-making; potential to share data with an HCP; and personal value attributed to mobile devices.

- *Support for cognitive decision-making* – dosage adjustment calculations in relation to self-management were identified as a key component of personal cognitive decision-making. The interviews conveyed the depth, complexity and frequency with which participants and their carers were making dosage decisions and adjustments based on blood glucose readings. Participants identified the potential for the development of mobile apps in order to support this.

"The only thing I think I really […] is rates of increase or decrease, I don't care about the numbers, I want to know what it's going to be in 20 minutes. Yeah, yes that's what I want to know and I want to know it now…" (50-year-old man).

There was also a sense of the scale of data that can potentially be recorded by a person with type 1 diabetes, and that a mobile app could provide motivation to continue to do this, especially if the data could provide meaningful feedback.

"To pull forward and give you some feedback so that, because the other thing is you don't get any feedback until your next visit and if your visit is in 12 months' time then the incentive to complete your record book I think is probably more difficult" (52-year-old man).

- *Potential to share data with an HCP* – this was seen as an important motivator in terms of receiving personal feedback, especially for emergencies and acute episodes.

  "The fact that I'm having to be in regular contact with one of the specialist nurses who needs to be informed of my ketone levels and glucose levels a good few times a day probably having that kind of application as long as the diabetes nurse had the same application I think to actually be able to quickly email data could be quite useful rather than actually spending the next 10–15 minutes actually texting out a message" (43-year-old woman).

- *Personal value attributed to mobile devices* – in addition to there being greater value attached to technology by younger participants, some of the older participants identified "technical personalities", who may be motivated to use a mobile app.

  "I should imagine someone who's really technical-minded then I think they could have a lot of fun, you know tracking patterns and trends and working out algorithms and things like that but for someone who is in their 50s or 60s who has just developed type 2 and then eventually is put on insulin and has to record glucose levels, I don't know, I don't know" (45-year-old woman).

What features would you like to see in the future development of mobile apps to support diabetes care?

The features that participants would like to see in the future development of mobile apps could be categorised under the following themes – safety-netting and feedback; these are specifically listed in *Table 7*.

Discussion

All of the apps reviewed within the study had simple functionality. The qualitative data analysis suggests that accuracy is important to the user, and entering personalised data quickly, efficiently and conveniently is also a key issue. There were data entry errors, especially with touchscreens, which can be exacerbated by complications of diabetes.

Visualising data

The reviewed apps were, in the main, limited in terms of functionality; for example, some had shortcomings in data handling, such as no capacity for retrospective data entry or editing of data, and many did not facilitate secure transmission of personal monitoring data. However, there were some features perceived as useful, such as the ability to be able to visualise graphical representations of personal trends. This is an important aspect of personal diabetes self-management and corresponds with the findings of the usability study carried out by Ciemans et al (2010), which suggests great potential if usability issues can be overcome by improvements in visualisation features for personal data analysis.

Demographic factors, feedback and communication

Participants identified the benefits that apps could offer to specific demographic groups, such as children and young people, and for all groups the potential for feedback and communication of personal data via an app to an HCP.

A small number of studies have explored the use of mobile apps by children and young people with diabetes, which focus on engagement with services and self-management strategies (Farrell and Holmes-Walker, 2011; Mulvaney et al, 2012). Results showed that mobile apps resulted in modest improvements in glycaemic control and were a reliable approach for engaging adolescents and young people. This demographic group are frequently lost to follow-up, especially at the transition between paediatric and adult diabetes service; this is a time when this group are susceptible to short-term complications, such as diabetic ketoacidosis.

Implications for clinical practice

The authors presented their work from this study to three community-based clinical diabetes nurse specialists who are members of the local Diabetes Nurse Network Forum. Based on the nurse practitioners' experiences of working with children and young people, who use electronic communication (SMS text or e-mail) as a key mode of communication, their perception was that using a mobile app to record personal data for school-age adolescents was more socially acceptable than, for

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example, a paper diary, and a potential incentive for engagement with self-management. The needs of a young person with diabetes entering university was given as an example of when personal routines may change, and the nurse practitioners identified that an app that provided personal feedback or can communicate with an HCP has a great deal of potential in this situation.

Nurse practitioners also suggested that many young people may be unaware of the potential use of mobile apps to support self-management of diabetes, and that the use of a mobile app was likely to have more uptake if this was supported by the HCP. This is an important consideration given that there are approximately 29 000 children and young people in the UK with diabetes (Diabetes UK, 2012a).

Many people with type 1 diabetes (of all ages) currently record a great deal of personal data to support personal decision-making, and there is recognition by the user of the potential of more efficient aggregation of this data and mobile apps to provide feedback and connect with HCPs for further support. These are important considerations for clinical practice, and HCPs will have personal development needs in terms of being up-to-date with current technologies. There may be a role for universities that promote research within this area to provide education and training. This is a rapidly evolving area, and the apps that are presented in this study have already been superseded. However, as an outcome of the study the authors have produced some general guidance for individuals with diabetes and practitioners on the features to consider when choosing a glucose-tracking app (*Table 8*).

Table 8. Considerations to be made when choosing a glucose-tracking mobile app.

Features	Considerations
● Blood glucose	– Does the app allow you to choose the appropriate units for blood glucose, such as mmol/L in the UK? – Is there an option to specify target levels for your blood glucose? – Does the app give any warnings if your blood glucose is particularly high or low?
● Carbohydrates	– Does the app let you record how much carbohydrate you have for a meal or snack? – Will the app let you record your carbohydrates in the same way that you count them, such as in grams or portions? – Is there an option to store your personal carbohydrate ratio?
● Insulin	– Does the app let you record how many units of insulin you take, and when? – Can the app give you advice on how much insulin to take, depending on your blood glucose and carbohydrate intake? – Can you specify what kind of insulin you are using, such as brand, bolus or basal? – If you take more than one insulin at the same time, does it allow you to record this? – Does the app let you record extra *ad-hoc* insulin injections rather than at fixed times of the day? – Can you record the injection site on your body that you used? This is useful for regular rotation
● Ketones	– Can the app record ketone measurements? – Does the app give advice on ketone testing?
● Reminders	– Does the app let you set reminders? For example, reminders could be useful if you have to produce a certain number of blood glucose results before your next clinic appointment

Limitations of the study

A limitation of this research project was that only iPhone apps were reviewed; previous work by the team has also included a systematic review of apps on the Android, Blackberry and Windows platforms (Garcia et al, 2011).

A further limitation of our study is that it was focused on people with type 1 diabetes. Work undertaken by Liang et al (2010), Lyles et al (2011), and Rollo et al (2011) suggests a significant and evolving role for mobile technologies to motivate the self-management strategies of individuals with type 2 diabetes. In addition, the authors' study did not take into consideration the cost to individuals of using mobile apps.

Conclusions and future research

This study reinforces previous studies regarding individual preference, visualisation of data on mobile devices and the potential to connect with younger people with diabetes (Farrell and Holmes-Walker, 2011; Lyles at al, 2011; Mulvaney et al, 2012). However, the authors identified some detailed usability issues, which will enable the team to undertake further research with users to result in better-designed mobile apps. These will support self-management strategies for individuals with type 1 diabetes as well as those with type 2 diabetes

in relation to personal monitoring data, allowing them to explore their data interactively from multiple perspectives. This will enable them to gain useful insight into how to manage their condition and provide purposeful information to share with a designated HCP for further support with personal decision-making. ■

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