Journal of Biomedical Informatics 43 (2010) S37–S40

Contents lists available at ScienceDirect

Journal of Biomedical Informatics

journal homepage: www.elsevier.com/locate/yjbin

# Designing mobile support for glycemic control in patients with diabetes

Lynne T. Harris [a,*], James Tufano [b], Tung Le [b], Courtney Rees [a], Ginny A. Lewis [c], Alison B. Evert [d], Jan Flowers [c], Carol Collins [e], James Hoath [f], Irl B. Hirsch [g], Harold I. Goldberg [g,1], James D. Ralston [h]

[a] Department of Health Services, University of Washington, 1959 NE Pacific Street, Magnuson Health Sciences Center, Room H-664, Box 357660, Seattle, WA 98195-7660, USA
[b] Biomedical and Health Informatics, Department of Medical Education and Biomedical Informatics, University of Washington, Box 357240, 1959 NE Pacific Street, HSB I-264, Seattle, WA 98195-7240, USA
[c] Department of Biobehavioral Nursing and Health Systems, University of Washington, Box 357266, Seattle, WA 98195-7266, USA
[d] Diabetes Care Center, UW Medical Center-Roosevelt I, 4225 Roosevelt Way N.E., Seattle, WA 98105, USA
[e] Department of Pharmaceutics, University of Washington, H-272 Health Sciences Building, Box 357610, Seattle, WA 98195-7610, USA
[f] UW Medicine Information Technology Services, 9725 3rd Avenue NE, Northgate Executive Center II, Seattle, WA 98115-2024, USA
[g] Department of Medicine, University of Washington, RR-512 Health Sciences, Box 356420, Seattle, WA 98195-6420, USA
[h] Group Health Research Institute, 1730 Minor Avenue, Suite 1600, Seattle, WA 98101-1448, USA

ARTICLE INFO

*Keywords:*
Diabetes
Chronic disease management
Clinical informatics
Telemedicine

ABSTRACT

We assessed the feasibility and acceptability of using mobile phones as part of an existing Web-based system for collaboration between patients with diabetes and a primary care team. In design sessions, we tested mobile wireless glucose meter uploads and two approaches to mobile phone-based feedback on glycemic control. Mobile glucose meter uploads combined with graphical and tabular data feedback were the most desirable system features tested. Participants had a mixture of positive and negative reactions to an automated and tailored messaging feedback system for self-management support. Participants saw value in the mobile system as an adjunct to the Web-based program and traditional office-based care. Mobile diabetes management systems may represent one strategy to improve the quality of diabetes care.



## 1. Project goals and design requirements

Our current healthcare delivery system, based on short and infrequent clinic encounters, does not meet the needs of many patients living with diabetes and other chronic conditions. Only one in eight US patients with diabetes is able to achieve target goals for blood sugar, blood pressure, and cholesterol [1]. Chronic disease management programs that incorporate mobile and Web-based technologies offer potential to shift the focus away from the clinic and towards patients' daily lives, where behavior change is actualized. As of 2009, 91% of US households had a mobile phone subscription [2] and 56% of adults had accessed the internet with a wireless device [3]. Mobile application downloads are projected to increase by 145% this year [4]. Along with this explosion in mobile technology, a range of new health management tools have proliferated. A keyword search for "medical" on iTunes currently returns 3337 iPhone applications [5]. Numerous Internet-enabled personal medical devices are now available, ranging from body scales [6] to sophisticated wearable physiologic sensors [7].

We previously designed and tested a Web-based diabetes program consisting of interactive disease management tools and secure messaging [8]. Patients could upload their glucose measurements to a shared electronic medical record using a wired interface to their home computer. A randomized trial of the program found a 0.7% decrease in Hemoglobin A1c, which was both clinically and statistically significant [9]. Qualitative interviews suggested the program fulfilled participants' unmet care needs [10]. Despite the overall success of the trial, only 43% of patients uploaded their glucose meter data. Participants cited the dependence on their personal computer for uploads as a significant barrier to usability.

As a next step, we sought to extend our Web-based system to mobile phones. HealthReachMobile is a suite of mobile phone applications designed to help patients with diabetes understand day-to-day trends in their blood glucose and communicate with care providers between office visits. A key design requirement was to provide feedback on the phone itself, minimizing the need for a computer or direct clinician involvement. This requirement distinguishes our system from several systems which use mobile phones primarily as a tool to upload glucose data to Websites or clinicians for further review [11–13]. In this paper, we describe end-user design evaluations of three features of our system: wireless

* Corresponding author. Address: 411W Lk Sammamish Pkwy SE, Bellevue, WA 98008, USA. Fax: +1 206 287 2871.
*E-mail addresses:* ltownsen@u.washington.edu (L.T. Harris), jtufano@u.washington.edu (J. Tufano), le@u.washington.edu (T. Le), crees@uw.edu (C. Rees), ginnyalewis@montanasky.us (G.A. Lewis), atevert@u.washington.edu (A.B. Evert), jflow2@u.washington.edu (J. Flowers), carolc3@u.washington.edu (C. Collins), hoath@u.washington.edu (J. Hoath), ihirsch@u.washington.edu (I.B. Hirsch), ralston.j@ghc.org (J.D. Ralston).
[1] Deceased author.

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doi:10.1016/j.jbi.2010.05.004

glucose meter uploads, automated self-management support messages, and blood glucose feedback displays for mobile phones.

## 2. Prototype description

### 2.1. System architecture

HealthReachMobile ran on three secure, HIPAA-compliant, servers. The first server acted as the domain controller and directory server. The second server hosted the mail and applications servers. The third server hosted patient-reported physiological data (Microsoft SQL Server 2007). The domain controller and applications server were isolated for security reasons, and the database server was isolated to maximize performance and future scalability. Microsoft Exchange Server (2007) and Windows Mobile phones (version 6 or higher, see Appendix, Fig. 1, for images) were chosen because of their support for push email, which enabled rapid two-way email communication.

### 2.2. Feature set 1: wireless glucose meter uploads

Our wireless upload solution included a One Touch glucose meter, a Windows Mobile smartphone, and a custom-built Bluetooth interface (Cyberfab, Crolles, France) to mediate communication between the meter and the phone. The Bluetooth interface was approximately $3'' \times 1''$. Patients transmitted data by launching an application on the phone, connecting their meter to the Bluetooth interface, and pressing a button to initiate the upload. Patients could not upload data directly from their meter to the computer, but could view their data through a Web interface once it had been uploaded.

### 2.3. Feature set 2: automated self-management support messages

Automated messages were designed to provide tailored, educational information related to diabetes (see Appendix, Table 1, for example messages). Message content was generated by a dietician, a clinical psychologist, and a diabetes management nurse. Messages were formatted as questions or statements followed by fixed response options. Responses triggered related follow-up messages in a branching chain. Maximal message chains were four levels deep. Certain messages relating to the management of hypo- and hyperglycemic messages would be sent only when a patient's uploaded readings were out of a specified target range. The system logged a patient's responses to various messages for later review by the case manager.

### 2.4. Feature set 3: blood glucose feedback displays for mobile phones

Trend graphs included monthly, weekly, and 24-h displays (Fig. 1). Tabular data included weekly and monthly averages, highs, lows, and standard deviations. Specific graphs were chosen based on user feedback in think-aloud design sessions and prior intervention studies by the research team. Feedback was displayed using HTML graphics embedded in email messages sent to the phone. Patients received the mobile phone feedback to complement more sophisticated graphical displays available in their Web-based electronic medical record. The graphics on the Web were customizable, but those on the phone were not.

## 3. Design evaluation

We performed two phases of design evaluation. The first phase (six participants) focused on the wireless upload and automated

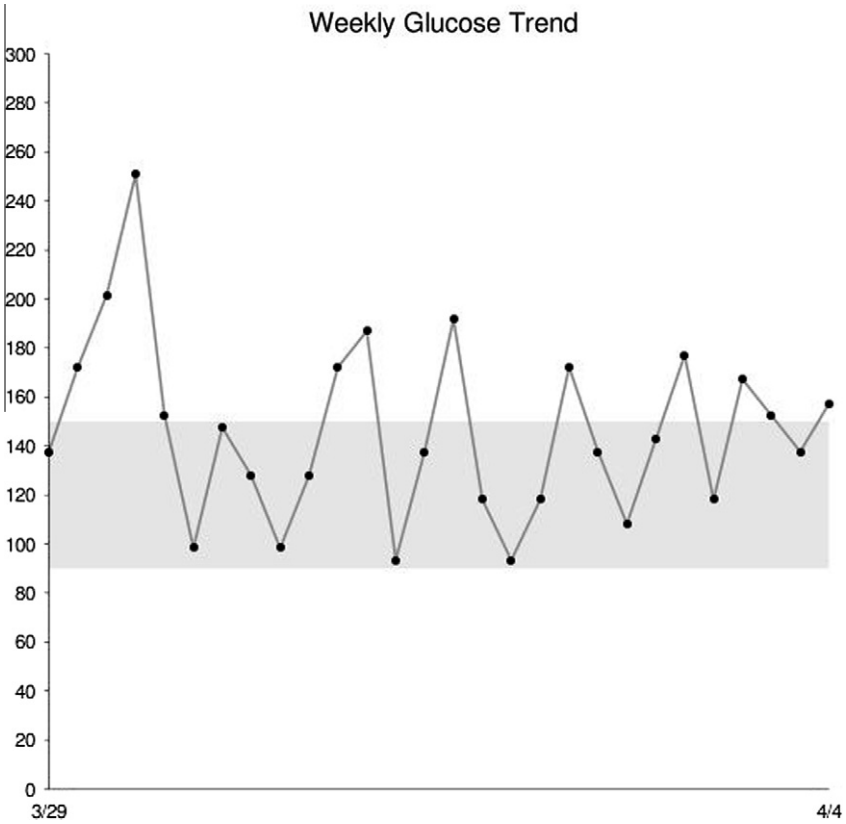


**Fig. 1.** Example blood glucose feedback display for mobile phones.

messaging features. Participants had either type 1 or type 2 diabetes and ranged between 18 and 65 years of age. Participants were recruited by email from several University of Washington clinics. Participants were observed and interviewed while using the prototypes under simulated conditions. A modified think-aloud design protocol [14,15] was used to elicit participants' perspectives about the prototype's design strengths and weaknesses and potential usefulness. A key strength of the think-aloud protocol is the ability to gain a clear picture of the user's thought process as they complete tasks, yielding rich qualitative insights and the rapid recognition of usability problems that may not be transparent to the designers. Sessions averaged 90 min and were video and audio-recorded. Transcripts of the audio recordings were open coded by three researchers to identify salient themes (see Appendix, Table 2, for codebook).

The second phase of our design evaluation (eight participants) focused on the mobile phone data displays. Participants had type 2 diabetes and ranged between 18 and 70 years of age. Participants were recruited by phone from the University of Washington General Internal Medicine Clinic. Participants had completed a 3-month pilot feasibility trial of the wireless glucose meter uploads and mobile phone data displays. Participants also had access to the Web-based electronic medical record and case management. Automated messaging was excluded from the trial based on negative user feedback from the earlier usability testing sessions. During post-trial interviews, each participant was first asked about their overall experience with the system. Participants were then presented with a paper printout of examples of the mobile phone data displays and asked to write on the page to identify areas of confusion and suggestions for modifications. Interviews were audio-recorded, transcribed, and open coded by three researchers (see Appendix for codebook).

## 4. Evaluation results

Our qualitative analyses revealed four key themes about the design of mobile applications for diabetes self-management support.

### 4.1. Wireless glucose meter upload through a mobile phone is convenient and easy

All six think-aloud design participants reported that the wireless upload process was convenient and easy. There were no criticisms of this feature in either design phase.

### 4.2. Value of the system tied to real-world relationships

Five of the six think-aloud design participants felt that the value of the automated messaging system was strongly tied to real-world relationships with care providers. One participant noted that the information exchanged using the system might improve the efficiency of in-person appointments:

> "It would be most helpful if... they could see these notes before I come in so that we can have a conversation about it and I don't have to re-explain"

Another think-aloud design participant envisioned the messaging system as a tool to work on one specific behavior change goal at a time, in collaboration with his care providers. One participant in the post-trial interviews felt that the feedback graphs would *only* have value in the context of a patient-provider relationship:

> "I think they're only valuable as they're linked to a discussion with a real person... You got to have a person."

### 4.3. Automated messages not useful as designed

Although all six think-aloud design participants found value in some of the components of the messaging system, users found a sizeable proportion of messages tested to be objectionable. Five participants felt that at least some of the messages were irrelevant to them. Two participants felt that some messages were better suited for newly-diagnosed diabetics. Three participants felt insulted, patronized, or scolded by specific messages. Four participants felt that some multiple-choice responses were insufficient, and required an "*Other*" option or the ability to add free text. Three participants felt that their need for the system would vary with the course of their illness, and would not want to receive messages on a fixed schedule. Two participants expressed a strong preference for patient-provider email over automated messaging.

### 4.4. Graphical and tabular feedback on phone was useful

In post-trial interviews, six of eight participants found value in the mobile phone feedback. The remaining two participants could not receive feedback on their phones due to technical issues, but found potential value in the graphics presented in the design session following the trial. One participant commented:

> "I liked the feedback because it showed me how certain activities and certain foods affected me."

One participant felt that the graphs were too small to read on the phone, but used the Web interface. One participant reported confusion about how to interpret some of the feedback.

## 5. Discussion and implications

Several key design recommendations emerge from our work. First, integrate mobile technology into diabetes care. Mobile glucose meter uploads and graphical and tabular data displays on the phone were the most desirable system features tested. Since this project was begun, two Bluetooth-enabled blood glucose meters have become commercially available [16,17]. Given that glucose meters are FDA-regulated medical devices, decoupling the meter from the data analysis software, as was done in our system, will enable the most rapid innovation. Although one medical iPhone application has been classified by the FDA as a class III medical device [18], this is the currently exception and not the rule. Second, build systems which connect patients to their healthcare providers. Finally, elicit user input early and often. We learned through design sessions that it would have been premature to test our automated messaging system without further research and user testing to improve message relevance. As studies of computerized physician order entry systems have shown, automatic alerts are frequently overridden or ignored by clinicians due to poor specificity and alert fatigue [19–21].

The present study had several limitations. Qualitative design research in a small sample is not intended to support formal hypothesis testing or generalizable claims of causality. Generalizability of our findings is also limited by self-selection bias; it is likely that our sample was more highly motivated to manage their health and had higher levels of technical literacy than the general population of patients with diabetes.

## 6. Overview of implications

Our results support further development and testing of wireless glucose meter uploads integrated with graphical and tabular feedback on mobile phones. Patients value systems which connect

them to their care providers; standalone mobile care management systems hold less promise for broad-based adoption.

## Statement of conflict of interest

The authors declare that there are no conflicts of interest.

## Acknowledgement

Funding for this work was provided by *Project Health Design*, a program of the Robert Wood Johnson Foundation.

## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jbi.2010.05.004.

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