Integration of Blood Glucose and Behavioral Data for Personalized Feedback: Iterative Design and Optimization of the MyDay Mobile App

Rachel B. Carroll[1], Douglas C. Schmidt[1], Korey K. Hood[2], Lori M. Laffel[3], Laura K. Williams[1], Sarah E. Vaala[1], Kevin B. Johnson[1], Bob McClellan[1], Yu Sun[4], Yaa Kumah-Crystal[5], and, Shelagh A. Mulvaney[1]

[1] Vanderbilt University, Nashville, Tennessee
[2] Stanford University School of Medicine, Palo Alto, California
[3] Harvard Medical School, Boston, Massachusetts
[4] California State Polytechnic University, Pomona, California
[5] Vanderbilt University Medical Center, Nashville, Tennessee

Abstract

This paper describes the development process of a mobile app called MyDay, which is a self-management problem solving tool for young people with type 1 diabetes (T1D). Individuals with T1D must perform many self-management tasks, including monitoring blood glucose (BG) several times each day to maintain in-target glycemic control. MyDay integrates BG data in real time with psychosocial and contextual data, such as mood, stress, location, and social context, and provides real-time feedback through the app. The purpose of integrating these data was to create personalized feedback for self-awareness of factors associated with diabetes self-management patterns and promote data sharing and problem solving. Iterative user-centered design cycles were used to document and/or troubleshoot feasibility and technical stability, optimize feedback for effective health communication through data visualization, identify barriers to app use, optimize assessment, and evaluate capability of the app as a problem solving tool. Each iterative design round identified technical and design issues that were addressed in subsequent rounds by working closely with adolescents, clinicians, and diabetes researchers. An *in vivo* case study was conducted at the end of the iterative cycles. Results from the iterative cycles and case study provided evidence of feasibility, engagement, and utility in order to advance to a pilot randomized controlled trial in future work.

Keywords Mobile app; Android; iOS; Type 1 diabetes; Ecological momentary assessment; user-centered; iterative design; feedback; data visualization.

1. Introduction

Type 1 diabetes (T1D) is an autoimmune disease where the body produces little to no insulin, necessitating multiple daily injections of insulin or insulin pump therapy for survival. A key issue for individuals with T1D is glycemic control. T1D patients monitor their blood glucose (BG) levels multiple times per day using BG meters and less frequently with the addition of continuous glucose monitoring devices. A 2-3-month average of glycosylated hemoglobin is assessed in clinic via the HbA1c test, which is indicative of overall BG control. In-target glycemic control is critical in delaying or avoiding complications, both short-term (e.g., hypo- or hyperglycemia, diabetic ketoacidosis) and long-term (e.g., retinopathy, kidney disease, neuropathy, cardiovascular disease) (1).

In addition to monitoring BG, other related tasks performed daily by individuals with T1D include counting carbohydrates and insulin self-dosing and administration. Support of self-management behaviors that increase in-target BG values is especially important in adolescents with T1D. These behaviors are important not only because of the long-term health impacts of inadequate glycemic control, but also because this population is at particularly high risk of struggling with adherence to their diabetes treatment regimen.

Barriers to Adherence. Maintaining diabetes adherence is challenging because of the frequency and complexity of self-management and also because tasks must be performed around meals, snacks, and exercise. Psychosocial and environmental factors, such as location, emotional state, social context, and other surrounding activities, can create barriers to diabetes treatment adherence. Moreover, disrupted self-management may be associated with daily living patterns, such as time pressures during certain times of day, social context, or around specific activities like sports practice (2).

Importance of Problem Solving Skills. Problem solving interventions have shown success in helping adolescents with T1D improve their self-management practices and health outcomes through reducing barriers to adherence (2, 3). Successful problem solving is predicated upon accurately identifying those barriers and patterns of behavior. Problem identification or problem awareness is the first step in the problem solving cycle. Based on previous research (3-6), improved recognition of how self-management is related to situational, contextual, and psychosocial factors should provide a data-based means to address the first step in problem solving, known as problem orientation, problem identification, or problem awareness. Through pattern recognition and problem awareness, the MyDay app was designed to improve diabetes self-management skills, through personalized real-time feedback and behavioral problem solving support. Behavioral pattern recognition and problem awareness are cognitively difficult for adolescents due to their normative developmental stage of higher-order executive functions, the multifactorial nature of causation, and the repetitiveness of self-management.

Ecological Momentary Assessment (EMA). EMA is a method that has shown promise in providing more accurate data for problem solving by systematically studying an individual in real-time or near real-time to more accurately assess and relate the experiences and environment of the individual to health behaviors and outcomes (7). EMA can help identify novel behavior patterns through data collection at either random or critical specified points over time (7-10). EMA assessments are collected close in time or at the time of events of interest, which helps minimize response bias that may otherwise occur using retrospective methods (7). Given the penetration of smart phone use in adolescents and emerging adults, momentary assessment can be feasibly implemented via smartphones.

Adolescents with T1D perform virtually all their self-management practices outside of a medical setting (e.g., they are expected to check their BG, count carbohydrates, and dose insulin while at home, school, or out with friends). To discern and address factors that interfere with appropriate diabetes self-management, potential barriers must be identified where and when they occur. EMA is an ideal tool for studying the interaction between person variables and the natural environment of health behaviors (11) and has been successfully used in studying diseases, such as asthma, cancer, eating disorders, and diabetes (12-15).

Our goal in designing the MyDay mobile app was to help create awareness regarding patterns of diabetes self-management and how those patterns relate to different aspects of their daily experiences. This paper explores the development and design of the app and the challenges faced when integrating BG data with behavior and communicating behavioral patterns to young people with diabetes. The MyDay technical structure, personalized feedback approach, and a case study are presented. Finally, lessons learned and future work are outlined for the continued development of the MyDay app.

2. MyDay App Behavioral and Design Goals

To facilitate awareness of psychosocial and contextual factors associated with BG data and self-management patterns, the development goals of the MyDay app were as follows:

- Integrate brief and valid behavioral assessments of psychosocial factors around meal and bedtimes when self-management tasks should occur
- Integrate real-time BG data
- Provide actionable personalized feedback via data visualization within the app
- Provide a means to share feedback from the app to enable problem solving and allow data sharing with others about personalized feedback
- Utilize common mobile platforms (e.g., iOS and Android) for maximal adoption.

3. Multidisciplinary Team

A multidisciplinary research team with experts in pediatric psychology, pediatric endocrinology, health communication, biomedical informatics, children's media, and computer science collaborated to create the initial specifications, prioritize and incorporate adolescent feedback, problem solve technical challenges, and design informative and engaging visual and text-based health communications. The team initially conducted a scoping review of existing apps and research literature related to potential momentary factors that influence self-management. After the set of potential foci for assessment were selected, the team explored availability of brief, valid behavioral assessments that could be utilized in the app's EMA features.

The initial preparation for the design process began with a thorough review of existing apps in the following domains: 1) momentary assessment, 2) psychosocial assessment, and 3) diabetes mobile apps. While there were a number of apps available, the review found that none of them met the needs described above. In particular, none of the apps provided an opportunity to integrate personal health data or information in the format and timing needed for the behavioral goals. The methods associated with five design iterations are described next. Summaries of the feedback and iterative modifications to the app are then described.

4. Iterative Design Process

This section describes the methods associated with each optimization cycle to provide the technical and behavioral support for later experimental evaluation of the app. The results of each iterative cycle are integrated into subsequent content-specific sections. Feedback, suggestions, and observations regarding what worked or did not work were incorporated into the design after each iteration. Results of the iterations and lessons learned related to assessment and feedback are summarized separately. See Table 1 for an overview of five design cycles.

Table 1: Overview of Five MyDay Design Cycles.

Design Cycle	Goal	Feedback Obtained from
1	Conduct rapid design feedback iterations on paper before development on mobile devices	Research team
2	Obtain feedback on the assessment items, response options, and feedback graphics before database and API	Adolescent participants

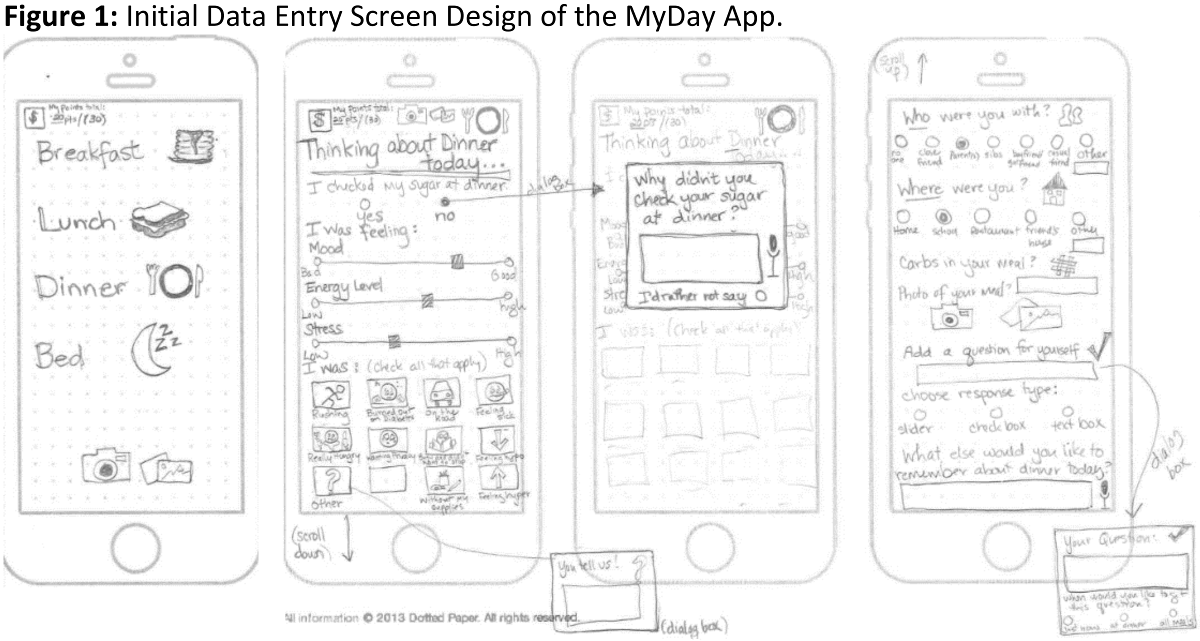
	development	
3	Obtain feedback on usability, comprehension of the intent of the questions, engagement, and suggestions for how to improve	Adolescent participants
4	Obtain feedback on experiences using the app and an infographic-style feedback summary of data	Adolescent participants
5	Test on-demand real-time visual feedback that integrated BG and psychosocial-behavioral-contextual data	Research team

Design Iteration 1: On Paper

Before the app was developed for use on mobile devices, the team conducted several rapid design iterations on paper. Paper interface designs were reviewed by the research team and suggested changes were made to the app. Mock ups of the main data entry home page and examples of assessment questions are shown in Figure 1. Several feedback graphics were explored to integrate many influences or factors simultaneously. These more complex graphics were abandoned as too complicated, so more simple and intuitive feedback graphics were created for rapid understanding of the depicted relationships.

To date, few assessments of psychosocial constructs have been validated for EMA. Self-reported psychosocial assessment instruments are often multifactorial and include a number of items that would be burdensome within a momentary assessment. Assessment items, however, were crafted based on previous validated approaches to the extent possible. For example, mood was assessed using the validated two-dimensional valence (negative/positive) and arousal (high/low) (16).

Figure 1: Initial Data Entry Screen Design of the MyDay App.



Design Iteration 2: A Working Prototype

Before committing time and resources on the database and software, the general format for the assessment, response options, and feedback graphics were tested in wireframes with adolescents. A group of six adolescents (67% male; Age (years): M = 15.0, SD = 1.1; HbA1c not obtained for this sample) with T1D were recruited within a pediatric diabetes clinic. Each teen was shown an iOS- or Android-version of an assessment, depending on which mobile platform he or she typically used. Each of them were then led through a semi-structured interview about the overall interface design, item language, types of feedback and data visualizations they would like, app data sharing (how and with whom), and their perceptions of how they could use the data to solve diabetes-related problems. Adolescent participants' feedback was incorporated into the design and used to create functional prototypes of the MyDay app.

Design Iteration 3: *In Vivo* Testing

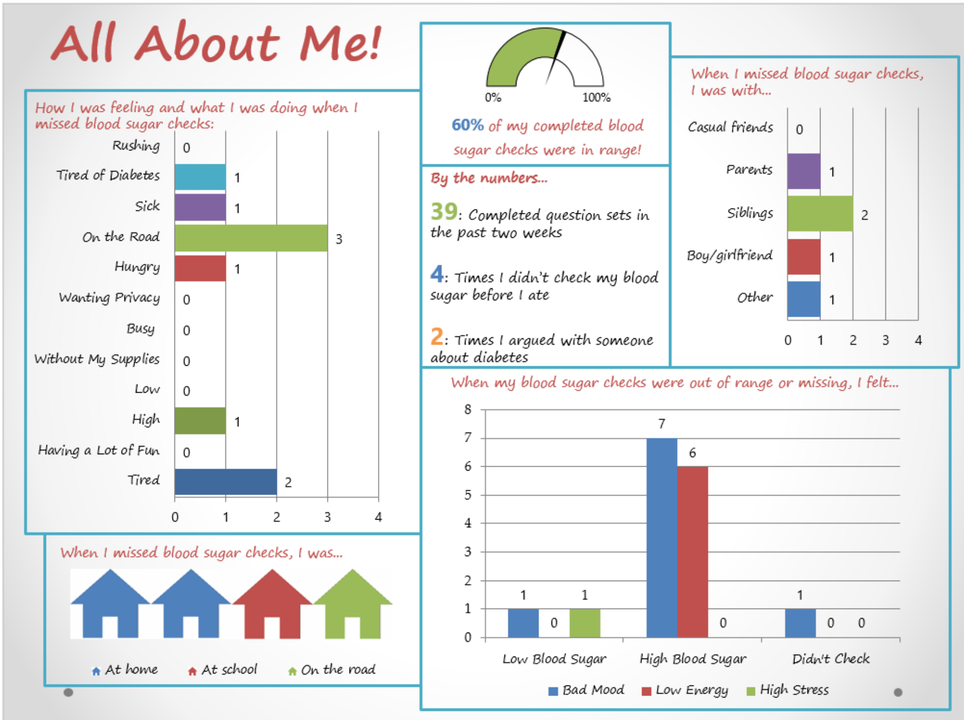
The first usable version of the MyDay app was tested by four adolescents (50% male; Age (years): M = 15.5, SD = 1.7; HbA1c: M = 8.0%, SD = 2.9%) recruited from the same pediatric diabetes clinic described above via clinician referral and interest cards. Each adolescent was given a Fitbit® wearable activity tracker (17) and asked to place it around their wrists to measure their physical activity. The goal was to link their activity patterns to BG changes and self-management behaviors, but these activity tracker data were not integrated into the MyDay system due to concerns regarding feasibility of tracker use.

Research staff first met with each adolescent to help them install the app. Research staff initially used the adolescent's Unique Device Identifier (UDID), a 40-character value that is iOS-device-specific, to create an installation link for iPhone. During subsequent rounds of testing iPhone and Android users could install MyDay via their respective app stores. Participants were then shown how to use the app, and after a use period of 8-9 days the participants discussed their experiences using the app. Data from this round of testing were primarily qualitative; while the responses entered for each of the four daily EMA entries were recorded, the main interests in this round of feedback were the MyDay app's usability, comprehension of the content and intent of the questions, engagement with the app, and suggestions for how the app could be improved. The modifications from the first round of prototype testing were implemented rapidly to allow a new round of field testing to begin as soon as possible.

Design Iteration 4: *In Vivo* Testing

For this iteration, eight adolescents (50% male; Age (years): M = 15.3, SD = 1.7; HbA1c: M = 9.6%, SD = 3.2%) were recruited using the same method. Each participant used the MyDay app between 7-14 days, and Fitbit® activity trackers were given to the first five participants enrolled to wear during their participation. As in the previous round of testing, research staff met with participants at the start of their time using the MyDay app to introduce the study. The participants were then interviewed by the staff again at the end of their period of use to record their experiences. To test a range of feedback graphics simultaneously, each participant was shown an infographic-style feedback summary of their data from the app during their interview. This draft summary, called "All About Me," was a visual representation of aspects surrounding their diabetes self-management, such as where they were when their blood sugar was high, the number of discussions they had about diabetes that week, or what barriers were in place when they missed a blood sugar check. A sample of an All About Me infographic is shown in Figure 2.

Figure 2: Sample of All About Me Infographic.



Design Iteration 5: Intensive Internal Testing

The remaining development consisted of 1) developing and implementing a suite of on-demand real-time visual feedback that integrated BG and psychosocial-behavioral-contextual data, 2) integrating the iHealth®(18) API to incorporate Bluetooth BG meter data with meal and bedtime data collected from MyDay, 3) creating a system for matching BG data from the meter to the correct MyDay assessment, and 4) implementing a method for users to share their data and graphical feedback. To provide rapid feedback on the validity of the BG data going into the system, an internal testing cycle was conducted with staff testing their BG levels and utilization of test solutions created to indicate high and low glucose. Moreover, the research team wanted to test the broadest range of mobile phone types and operating system versions within a controlled testing environment.

Seven research team members, each using a different combination of mobile device type, mobile platform, and operating system version, were given the Bluetooth meters and asked to submit data on a regular basis using the MyDay app and the BG meter. Submitted values were intentionally varied to test different patterns of emotional states and environmental factors, and standardized glucose solutions were used to simulate out-of-range blood sugars. These entries were also recorded manually in a paper form so the data being displayed in the feedback could easily be compared to what should have been there.

During this evaluation process, the team continuously tested the accuracy of the data being returned from the app, the clarity and ease of understanding of the graphical feedback, and the stability of the MyDay app's performance under different potential use situations. Complex scenarios were tested to ensure the feedback graphs updated as intended. For example, some research app testers did not upload meter data for several days to see how graphs updated after the time delay. Others neglected to submit a meal time or skipped items within an assessment to test out various displays. The result of this internal testing process was a final prototype of the MyDay app that was deemed ready for a larger-scale field test.

5. EMA Assessment: Summary of Design Modifications and Key Challenges

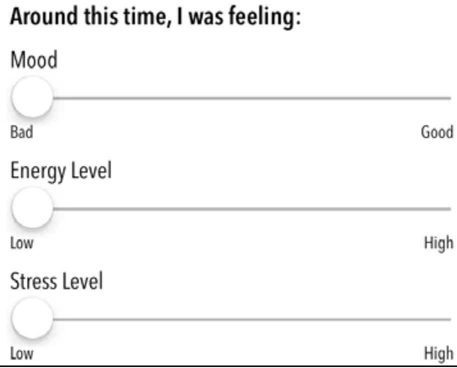
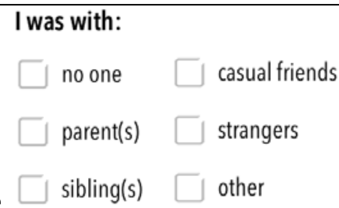
The MyDay administration interface was designed to provide flexible creation of data collection content, format, frequency, and timing. Data collection based on photos, rewards for data entry in the form of points, and data entry notifications were administrative features designed to be modified based on research and implementation needs.

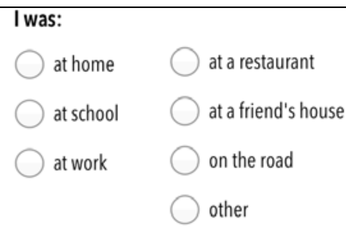
All daily assessments were available for data entry before or after a notification time for a full calendar day, from midnight to midnight; early rounds of testing showed that adolescents have highly variable daily schedules, even during the school year. Users received four reminder notifications per day to submit their assessments. The timing of each notification was tailored to each individual's indicated mealtimes and bedtime. This daily assessment entry deadline was problematic for some users, especially over winter and summer school breaks when they were awake past midnight more often. During the initial 2-3 days of the protocol these data were monitored, and the case study participant described in Section 9 was contacted for troubleshooting if there were apparent missing data.

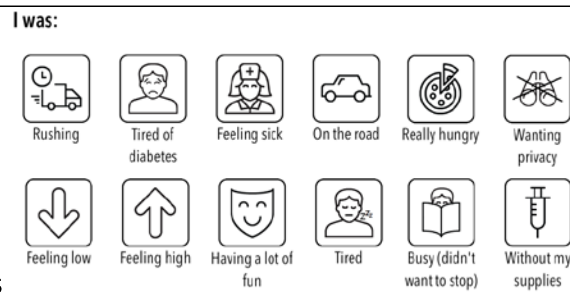
Each mealtime assessment asked the same set of questions. The assessment was kept as brief as possible with the goal of completing an assessment in less than one minute to help maintain engagement and minimize response burden. The fourth assessment, at the end of day, contained more retrospective items that considered the day as a whole and attempted to promote positive psychology. See Table 2 for a list of data collection elements.

Table 2: Data Collection Elements and Assessment Types.

Assessment Type	Data Collection Elements
Meal, Bed, and Snack	**My blood sugar BEFORE mealtime was:** I did not check
Meal, Bed, and Snack	**Carbs:** I did not count I did not eat
Meal, Bed, and Snack	What time did you eat?
Meal, Bed, and Snack	**Photo of what I ate:** Image Review
Meal, Bed, and Snack	Did you take insulin?

<table>
<tr><td>Meal and Bed</td><td>
</td></tr>
<tr><td>Meal</td><td>

People</td></tr>
<tr><td>Meal</td><td>

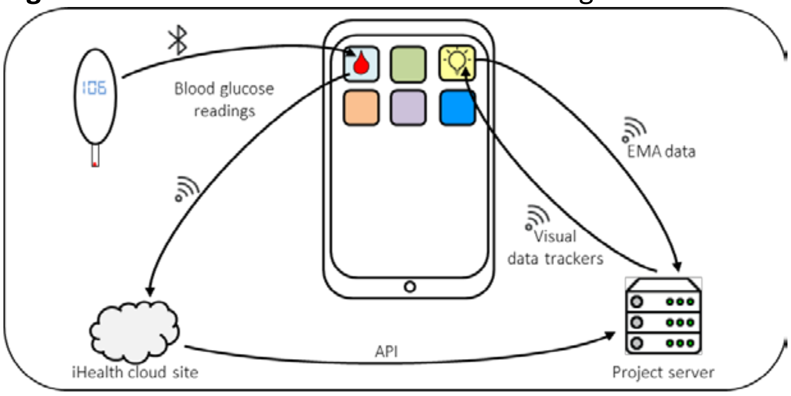
Place</td></tr>
<tr><td>Meal</td><td>

Barriers</td></tr>
<tr><td>Bed</td><td>Today I had an experience about diabetes that made me feel:</td></tr>
<tr><td>Bed</td><td>If you did, who was involved?</td></tr>
<tr><td>Bed</td><td>Do you want to remember anything else about this experience?</td></tr>
<tr><td>Bed</td><td>What was the best thing about today?</td></tr>
<tr><td>Bed</td><td>What else would you like to remember about today?</td></tr>
</table>

A question was added to each mealtime assessment about the time of the meal, to allow the system to link the correct meter reading to each meal. If the user did not report a time for their meal but did report that they ate, the default in-app notification time was used in lieu of an actual mealtime, and the system would look for values within one hour before or after that time. For the bedtime assessment, the system used the last glucose value of the day after 8:00 p.m. If a bedtime value also matched a mealtime value (e.g., a check at dinner after 8:00 p.m. with no later checks), the BG value was recorded as a mealtime glucose value and the bedtime assessment for that day recorded as a missed glucose check. The MyDay system scanned for matches any time new data, EMA or BG, were added to the server; when a new

MyDay assessment was added, the system looked for unmatched glucose values that would fit the criteria, and when new glucose data were added, it searched for MyDay assessments that did not currently have an associated glucose reading. This process is also shown in Figure 3.

Figure 3: Process of Blood Glucose Data Integration.



To accommodate for adolescents' inconsistent eating habits, an on-demand "Snack" assessment, an abbreviated version of a mealtime assessment, could be completed an unlimited number of times per day to gain information on non-mealtime BG and ecological factors. An "I did not eat" option was added to encourage participants to complete a mealtime assessment even when a meal was not actually eaten; habitually skipped meals could be a factor for some individuals related to more frequent high blood sugars.

Young participants were frequently unable to use the Fitbit® at the very times when they were most active. For example, a dance instructor would not allow one adolescent to wear the tracker during class, and a football player's Fitbit® frequently fell off during practice. Though physical activity plays an important role in BG patterns, the research team decided to stop asking participants to use a Fitbit® activity tracker, focus on other potential issues that influence self-management and glycemic control, and revisit how to better integrate exercise issues in subsequent versions.

6. Real-Time Blood Glucose Integration: Summary of Technical Considerations and Challenges

A key challenge faced by technology designers, researchers, people living with diabetes, and their families is the lack of simple and direct access to BG data from devices (19). Self-reported BG logs have been shown to be inaccurate, with individuals often misreporting values, forgetting to enter data, omitting undesirable readings, or making up values (20). Real-time BG data integration into MyDay was made possible by the iHealth® BG5 Bluetooth glucometer, a commercially-available meter. This glucometer eliminated the need for self-reported BG data.

Using the most recent version of the app, iHealth®'s relatively new meter with an open API was incorporated that integrated real-time BG data as feedback in the app. The glucose meter connected to an Android phone or iPhone via a Bluetooth connection. Test users paired the meter to their mobile device via Bluetooth, and the accompanying meter app automatically pushed de-identified data to the iHealth® secure cloud site via a cellular or Wi-Fi data connection. When a BG test was performed while the meter was synched to the phone, the meter's accompanying app automatically uploaded the value to the company secure cloud server.

The Bluetooth meter did allow for standalone BG monitoring when the meter was not paired to a mobile device; those values were pushed to the company cloud site the next time the user paired and synched the meter. Every time new values were updated, the meter API securely sent the value to the MyDay server, where it was recorded to the MyDay database. All glucose values were collected, although the MyDay assessment focused on mealtimes and bedtime. In order to be considered a mealtime glucose value, the MyDay system looked for the most recent glucose reading within one hour before the user-reported time of the meal; this window was based on the recommendation of diabetes clinicians on the research team. The iHealth® API was used to acquire glucose readings in real time and subsequently integrate the data into the MyDay app's graphs and logbook.

7. Personalized Real-Time Feedback: Design Considerations and Key Challenges

The goal of creating personalized feedback was to communicate patterns of BG and how they relate to the adolescents' behavior to ultimately help them become aware of how and where they could improve problems in their self-management. In earlier rounds of testing adolescent participants were shown a sample of a draft summary "All About Me" infographic during enrollment and told that they would receive a custom version using their own data. In obtaining iterative feedback from adolescents, however, the asynchronous graphical feedback was viewed as limited in promoting engagement because it was too far removed from actual events. Individuals who used the MyDay app for more than one week reported losing interest in submitting EMA assessments because they could not see how their data trends were changing over time.

The original intention was to provide an All About Me data summary to each user on a weekly or biweekly basis. User feedback prompted thinking about ways to provide more immediate feedback within the app via graphical communication. Moreover, participants repeatedly demonstrated that they would benefit from more types of immediate and real-time feedback regarding their data from the MyDay app. For example,

1) *"It would be cool if you could (see different graphs by day)."*
2) *"Show (graphs) by day and kind of just scroll down to each meal?"*
3) *"It would be kind of interesting to see how many times when I was rushing, how many times I was high versus in range versus low. Compare those contexts."*

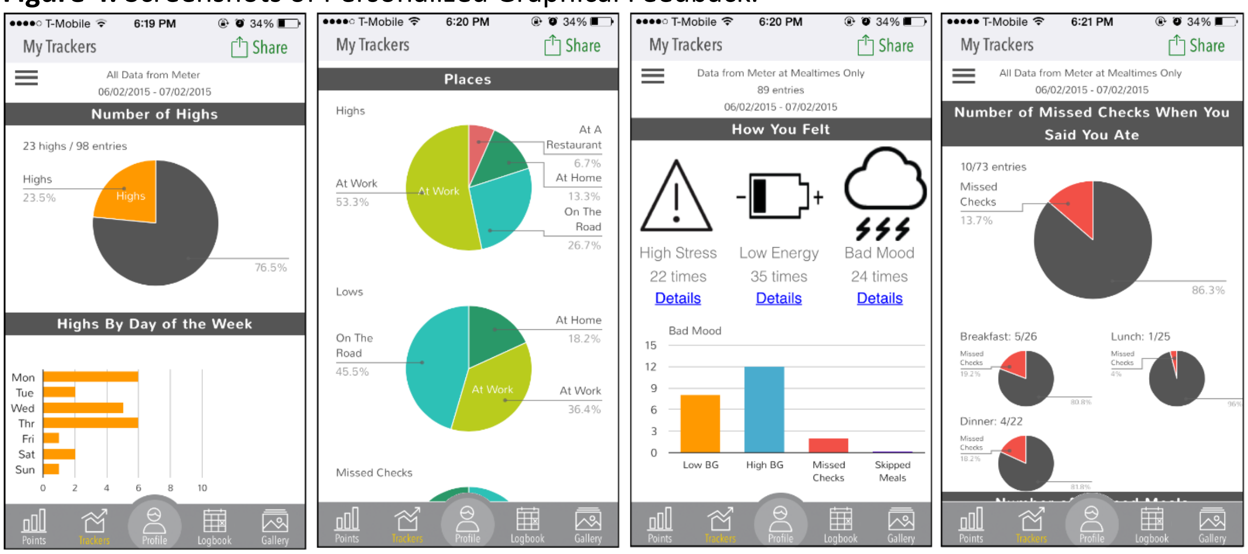
Due to the participant feedback received, substantial changes were made to MyDay's approach to graphical feedback by integrating a greater variety of feedback that was viewable through the app itself. A menu with the following eight tabs was introduced: Home, Good News, Highs, Lows, People + Places, Stress + Energy + Mood, What's Going On, and Missed BG + Meals. Integration of BG values with psychosocial and emotional data was provided as feedback within feedback in the app, and all BG values were recorded to the MyDay logbook. After the data from different sources were matched, the app provided immediate feedback on various combinations of BG data and relevant factors such as time of day, day of the week, social context, physical context, and mood and stress, as described further in Table 3 and Figure 4.

Table 3: Descriptions of Graphical Feedback Domains.

Feedback Menu	Description of Graphical Feedback

Home	Overall summary and week by week comparisons of low, in range, and high BGs
Good News	Badges for meeting the criteria for BGs in range, low stress, high app use, good BG average, and high number of BG checks; best things from the past 7 days
Highs	Overall high BGs and by day of the week and time of day
Lows	Overall low BGs and by day of the week and time of day
People + Places	Top 3 most frequently reported people and places displayed with BG highs, lows, missed BG checks, or skipped meals
Stress, Energy, Mood	High stress, low energy, and bad mood displayed with BG highs, lows, missed BG checks, or skipped meals
What's Going On	Top 3 most frequently reported barrier icons displayed with BG highs, lows, missed BG checks, or skipped meals
Missed BG + Meals	Meals eaten with no BG check, skipped meals, and missing app entries

Figure 4: Screenshots of Personalized Graphical Feedback.



All available BG values, as opposed to only mealtime BGs, were used in the data visualizations when possible. Some graphs depended on self-reported mealtime data, however, so they were limited to those time points with self-report. With a few exceptions (e.g., missed app entries and skipped meals), the feedback focused on integration with BG data because it was the most salient data to help users identify patterns in their diabetes self-management. In particular, the BG data helped users see where they were, who they were with, how they were feeling, or what was going on around them when they missed BG checks or when their blood sugars were out of target range.

MyDay graphical feedback was a major focus for the architecture of the app's assessment questions and design. The graphical information within the feedback was organized to facilitate best practices in personalized feedback: rapid understanding, reveal novel patterns and associations, provide meaningful information, and provide real-time updates (21). Participants also received feedback on how many entries they completed in the form of points and could look at a gallery of photos they had taken at any time. Any of the eight feedback pages and the points, logbook, and gallery pages could be spontaneously shared via text, email, or social network.

8. Final Technical Specifications

The MyDay mobile app was written in Java for Android and Objective-C for iOS. The MyDay server application was written in Ruby On Rails (v4.1) with a PostgreSQL database backend and provided an administrative web interface for managing users and content, as well as an API for serving requests to users' mobile devices. The app communicated with a third party API for the collection of Bluetooth BG meter values. All communications were handled through secure SSL communications with mobile connections managed with temporary authorization tokens.

9. Case Study

As an initial test of the app, a case study was conducted to provide in-depth *in vivo* data and user feedback. The analytic goals of the case study were to examine the feasibility of data collection and behavioral sampling schedule (at each meal and bedtime) over the course of four weeks and explore engagement with the app and its features such as the graphical feedback and sharing. A 14-year-old male with T1D agreed to use the app in order to help identify technical, communication, behavioral, and implementation issues for one month.

Multiple relevant patterns were identified in his use of the app and in his graphical feedback that indicated protective and risk-related patterns. By the end of the one-month study period, the case study user had completed 87% (95/109) of expected entries. Eleven of the fourteen missed entries were missed at bedtime. This individual reported going to bed after midnight most nights and forgot to enter bedtime information before the next calendar day. He checked his BG 70 times over one month for an average of 2.3 checks per day and missed 42% of his expected mealtime BG checks. The case study took place during summer, and not surprisingly his data patterns did not change from weekday to weekend and indicated that he was at home for every entry. Most (58%) of his high BG values were at nighttime. Eighty percent of his morning BGs were low, which is over three times more often than any other time of day. He also reported skipping most meals at breakfast (8/27) compared to lunch (5/27) or dinner (0/27). Regarding feedback about the app itself, this participant reported he liked seeing the overall BG feedback on the home page with his low, in range, and high blood sugar percentages combined. He thought the icons used throughout the app were easy to understand. The feedback helped him identify self-management patterns such as he was "always low in the morning" and "high at dinner." Another data pattern relevant for problem solving was that he missed his mealtime BG check 9/28 times when he had low energy. He reported that the Stress + Energy + Mood feedback page was the most interesting page because he realized stress affected his numbers and thought the feedback in general was "really cool."

Research staff also interviewed the case study participant's parent to obtain general feedback and insights regarding her son's use of MyDay and to explore ways that a parent and teen spontaneously interacted about the data and app. The mother reported that MyDay is "awesome" because it is used on the phone, something her son always has with him, and is a discrete way to keep his information close by. She thought that the MyDay app could be helpful for her son's awareness of self-management and problem solving around diabetes because it was personalized and worked with his data. After looking at the graphical feedback in the app, the parent and teen reported discussing how his BG values were higher than expected and how it helped him adjust his self-care to address that issue. The parent reported that she was "somewhat" involved in her son's use of the MyDay app in the past month; they looked at the graphical feedback twice, and she reminded him to complete entries some in the first week. When asked what she would tell another parent whose child is going to use the app, she replied they would like it and that it is the "the way of the future."

10. Discussion and Implications

Initial feedback and data from iterative design cycles and a case study showed the potential for the MyDay mobile diabetes app to integrate bio-behavioral information for real-time personalized feedback. Predictable and regularly scheduled multiple daily momentary assessments were feasible and provided novel insights for adolescents with T1D about their self-management patterns. The case study confirmed initial acceptability, feasibility, and the utility of the app in identifying novel behavioral targets for problem solving. The design process has resulted in a readily accessible and comprehensive program for young people with T1D to help them identify personally relevant data patterns and behaviors that may impact their self-management practices and BG values.

Integrative physiological and behavioral feedback using real-time mobile technology enhances the potential impact of feedback on health behaviors, allows for just-in-time communications to support awareness and behavior change, and promises to reinvigorate the science of human feedback in healthcare. The evidence base for, and potential of, momentary assessment is also growing rapidly. The MyDay mobile app represents an example of a hybrid human-reported and automated data collection system. We anticipate that in future versions the self-report burden will be offset to some extent by using background data collection, proxy variables or physiological assessment for some relevant factors such as stress, GPS for location, or inference of social context using multiple time-location variables. The validity and reliability of many proxy variables have not been well established. Finally, it is likely that a relevant core set of human experiences will never lend themselves to accurate assessment using unobtrusive proxy variables or triangulation using background data from mobile devices.

Future development and evaluation work planned for MyDay include 1) integration and experimental testing of the MyDay app and data within a problem solving system to support data interpretation and implementation of goals identified from the EMA and 2) collaboration with clinicians to explore clinical utility and associated modifications needed for clinical workflow implementation (2, 22). Integration into clinical practice will require additional clinic-based design cycles and integration of data valued by clinicians.

Acknowledgments

This research was supported by National Institutes of Health (DP3 DK097706) awarded to Dr. Mulvaney and by (CTSA UL1TR000445) awarded to Vanderbilt University.

References

1. Centers for Disease Control and Prevention: *National diabetes fact sheet: national estimates and general information on diabetes and prediabetes in the United States*. Atlanta, GA: U.S. Department of Health and Human Services, 2011.
2. Mulvaney SA, Rothman RL, Osborn CY, et al.: Self-management problem solving for adolescents with type 1 diabetes: Intervention processes associated with an internet program. *Patient Education and Counseling.* 2011, *85:*140-142.
3. Mulvaney SA: Improving patient problem solving to reduce barriers to diabetes self-management. *Clinical Diabetes.* 2009, *27:*99-104.
4. Glasgow RE, Fisher L, Skaff M, Mullan J, Toobert DJ: Problem solving and diabetes self-management. *Diabetes Care.* 2007, *30:*33-37.
5. Hill-Briggs F, Cooper DC, Loman K, Brancati FL, Cooper LA: A qualitative study of problem solving and diabetes control in type 2 diabetes self-management. *Diabetes Educ.* 2003, *29:*1018-1028.
6. Wysocki T, Iannotti R, Weissberg-Benchell J, et al.: Diabetes problem solving by youths with type 1 diabetes and their caregivers: measurement, validation, and longitudinal associations with glycemic control. *Journal of Pediatric Psychology.* 2008, *33:*875-884.
7. Shiffman S, Stone A, Hufford M: Ecological Momentary Assessment. *Annual Review of Clinical Psychology.* 2008, *4:*1-32.
8. Connelly K, Stein KF, Chaudry B, Trabold N: Development of an Ecological Momentary Assessment Mobile App for a Low-Literacy, Mexican American Population to Collect Disordered Eating Behaviors. *JMIR Public Health Surveill.* 2016, *2:*e31.
9. Pike JR, Xie B, Tan N, et al.: Developing an Internet- and Mobile-Based System to Measure Cigarette Use Among Pacific Islanders: An Ecological Momentary Assessment Study. *JMIR mHealth uHealth.* 2016, *4:*e2.
10. Mulvaney SA, Rothman RL, Dietrich MS, et al.: Using mobile phones to measure adolescent diabetes adherence. *Health psychology.* 2012, *31:*43-50.
11. Dunton GF, Atienza AA, Castro CM, King AC: Using ecological momentary assessment to examine antecedents and correlates of physical activity bouts in adults age 50+ years: a pilot study. *Annals of Behavioral Medicine.* 2009, *38:*249-255.
12. Anhoj J, Moldrup C: Feasibility of collecting diary data from asthma patients through mobile phones and SMS (short message service): Response rate analysis and focus group evaluation from a pilot study. *Journal of Medical Internet Research.* 2004, *6:*e42.
13. Bielli E, Carminati F, La Capra S, et al.: A Wireless Health Outcomes Monitoring System (WHOMS): development and field testing with cancer patients using mobile phones. *BMC Medical Informatics and Decision Making.* 2004, *4:*7.
14. Helgeson VS, Lopez LC, Kamarck T: Peer relationships and diabetes: retrospective and ecological momentary assessment approaches. *Health psychology.* 2009, *28:*273-282.

15. Hilbert A, Rief W, Tuschen-Caffier B, de Zwaan M, Czaja J: Loss of control eating and psychological maintenance in children: An ecological momentary assessment study. *Behaviour Research and Therapy.* 2009, *47:*26-33.
16. Russell JA: A Circumplex Model of Affect. *Journal of Personality and Social Psychology.* 1980, *39:*1161-1178.
17. *Fitbit, Inc.* Retrieved 9/1/16, 2016 from www.fitibt.com
18. *iHealth Labs Inc.* Retrieved 9/1/16, 2016 from https://ihealthlabs.com
19. Kumah-Crystal Y, Mulvaney SA: Utilization of blood glucose data in patient education. *Current Diabetes Reports.* 2013, *13:*886-893.
20. Guilfoyle SM, Crimmins NA, Hood KK: Blood glucose monitoring and glycemic control in adolescents with type 1 diabetes: meter downloads versus self-report. *Pediatric Diabetes.* 2011, *12:*560-566.
21. Polonsky WH, Fisher L: When Does Personalized Feedback Make A Difference? A Narrative Review of Recent Findings and Their Implications for Promoting Better Diabetes Self-Care. *Current Diabetes Reports.* 2015, *15:*1-10.
22. Mulvaney SA, Rothman RL, Wallston KA, Lybarger C, Dietrich MS: An internet-based program to improve self-management in adolescents with type 1 diabetes. *Diabetes Care.* 2010, *33:*602-604.