Usability and Feasibility of PmEB: A Mobile Phone Application for Monitoring Real Time Caloric Balance

Christopher C. Tsai[1], Gunny Lee[2], Fred Raab[3], Gregory J. Norman[3], Timothy Sohn[4], William G. Griswold[4], Kevin Patrick[3]

[1]*Decision Systems Group, Brigham & Women's Hospital, Boston, MA 02115 USA*
[2]*SCIL Group, Stanford University, 353 Serra Mall, Stanford, CA 94305 USA*
[3]*Family and Preventive Medicine, University of California, San Diego, CA 92122 USA*
[4]*Computer Science and Engineering, University of California, San Diego, CA 92122 USA*

ctsai@dsg.harvard.edu, gulee@stanford.edu, {fraab, gnorman, kpatrick}@paceproject.org
{tsohn, wgg}@ucsd.edu

Abstract

Obesity is a major public health challenge with over 65% of U.S. adults either overweight or obese. Estimated annual costs of obesity are around $78.5 billion. Self-monitoring is a critical skill for successful weight management. However, self-monitoring is labor-intensive and compliance is often difficult. In this paper, we describe the Patient-Centered Assessment and Counseling Mobile Energy Balance (PmEB) cell phone application that allows users to self-monitor caloric balance in real time. We developed and applied a four-phase iterative research and development methodology. We conducted a usability study and a preliminary feasibility study. The one month feasibility study measured compliance and satisfaction among a sample of 15 participants randomized to one of three groups: 1) a paper diary group, 2) a PmEB group with one daily prompt, and 3) a PmEB group with three daily prompts. PmEB scored highly on usability, compliance, and satisfaction. In addition, cell phone group users scored PmEB the same as or better than Paper Group members scored the paper diary in nearly all categories. Thematic analysis of comments revealed very positive reviews of PmEB as well as areas for improvement. PmEB is both usable and feasible for self-monitoring in weight management, and our iterative pilot study methodology was effective in improving its usability.

1. Introduction

About 65% of U.S. adults are currently overweight or obese. Obesity increases risk for many chronic diseases such as cardiovascular disease, diabetes, and numerous cancers. Estimated annual costs of obesity in the U.S. in 1998 was about $78.5 billion [9], with half paid by Medicare and Medicaid, and the remainder paid by private sources and out-of-pocket. Diet and physical inactivity are the main modifiable determinants of obesity [3]. From the National Weight Control Registry [25], men and women who have maintained at least a 30 pound weight loss for a minimum of one year report monitoring their weight on a daily or weekly basis. Overall, self-monitoring has emerged as a critical skill for obesity management [25], [15]. However, detailed self-monitoring is labor-intensive and compliance by users is relatively low [8].

The rapidly developing field of ecological momentary assessment (EMA) can contribute to the solution to the challenge of self-monitoring. EMA is a method increasingly used by behavioral researchers for the collection of self-report data on people's experiences as they go about their everyday activities [22], [23]. Frequent instantaneous reports of behavioral phenomena have been shown to minimize recall bias and more faithfully represent the true natural history of transitory states [21]. In addition, distributing smaller amounts of data collection throughout the day instead of larger amounts at rigid times or locations may decrease participant burden.

The promise of mobile technologies in health interventions is currently best represented by Ecological Momentary Intervention (EMI)[14]. EMI borrows implicitly from EMA, but also explicitly includes intervention as a focus. EMI is "just in time" prompting for a behavior change based upon a set of predefined conditions. For example, a computer can be programmed to monitor for changes in everyday activities. Based on the values measured, it can also proactively present tailored information that may lead to health-related behavior changes [7].

The ubiquity of mobile phones combined with their increasing computational and network communication capabilities present an obvious opportunity for EMI applications. First, the always-carried and always-on nature of mobile phones means that users can self-

monitor *in situ* at their convenience throughout the day. Second, the increased processing power of mobile phones allows for more sophisticated assessment and intervention applications. Third, network capabilities allow for data to be remotely processed on a server. These characteristics of mobile phones satisfy the requirements of EMI.

As the technology for context-aware applications continues to be developed, pilot studies are needed to lay the groundwork for assessing usability and feasibility. For these reasons, we investigated the usability and feasibility of mobile phones as a tool for monitoring eating and exercise behavior in real time. Real-time data capture allows for real-time data analysis and interventions – the basis of EMI.

Through four phases, we iteratively designed, developed and evaluated PmEB (Patient-Centered Assessment & Counseling Mobile Energy Balance). The first three phases focused on employing human-computer interaction methods to guide the evolution of our mobile phone prototype. In the fourth phase, we conducted a feasibility study with fifteen clinically overweight and obese participants that included a month-long deployment.

In this paper, we first discuss related work and the design and implementation of PmEB. Then, we describe the four-phase development methodology. The findings of the first three phases, first detailed in an earlier work-in-progress paper [11], are summarized. Next, we report findings from our feasibility study. Finally, we discuss future work and conclusions.

2. Related Work

The results of past EMA research only partially inform EMI research for several reasons. First, most EMA studies have used the Personal Digital Assistant (PDA) platform. For example, Intille et al. describe a PDA application designed to encourage better dietary decision making through just-in-time motivation at the point of food purchase [7]. One exception is the work of Collins et al, who compared the benefits of cell phone monitoring versus paper-and-pencil monitoring of alcohol consumption [4]. Meanwhile, technological improvements and higher adoption rates are making mobile phones the platform of choice.

Second, by its nature, EMA research is focused on assessment, and not intervention. Specifically, while there have been studies to assess variables associated with diet, no studies have been published that test applications to intervene on dietary or physical activity behavior.

Finally, methods for EMI research are still in their infancy, especially in systems that combine EMA and EMI. Usability will be a key factor for a device with a small screen that may require multiple interactions each day to serve both assessment and intervention functions.

Despite this need, very little of the website-focused usability literature has been translated and tested on mobile, ubiquitous platforms. Part of the challenge stems from the ubiquitous characteristic of mobile technology that is very different from traditional web-based technology. Since a cell phone might be carried around with you all day, it has the potential to disrupt your daily activities. Sholtz and Consolvo have pushed to develop a discipline for ubiquitous computing evaluation [18], but published progress remains at the conceptual level. Likewise, while we are aware of numerous other ongoing projects, use of systematic mobile usability methodologies have yet to be found in the literature as of October, 2006. As applications in EMI begin to emerge in the literature [2], [20], [24], there is a growing need for the development of usability and feasibility research methodologies for mobile health interventions.

3. The Design and Implementation of PmEB

In this section, we describe the overall system design, the web-based setup process, and the mobile client application.

System Design

The PmEB system consists of a client application running on the user's mobile phone, a server application running on a web application server, and a web-interface that allows users to register and personalize the mobile client (See Figure 1).
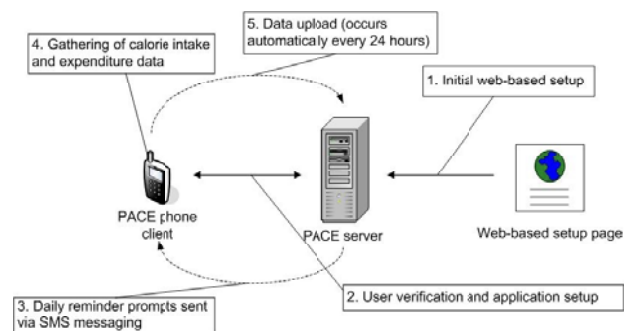

Figure 1 - Overview of PmEB system

We built the client application using Java 2 Mobile Edition (J2ME) and the server application using Tomcat. Theoretically, the application can run on any J2ME-compliant phone. It was tested on the Nokia 6600, Motorola V300, and Motorola RAZR. We opted to use the Motorola RAZR platform for our final evaluation study due to its large screen and convenient form factor. The client application is the primary way the user interacts with the PmEB system. The server application has three functions: to send reminder messages to the clients to update caloric information, to store the food and

| (a) | (b) | (c) | (d) |
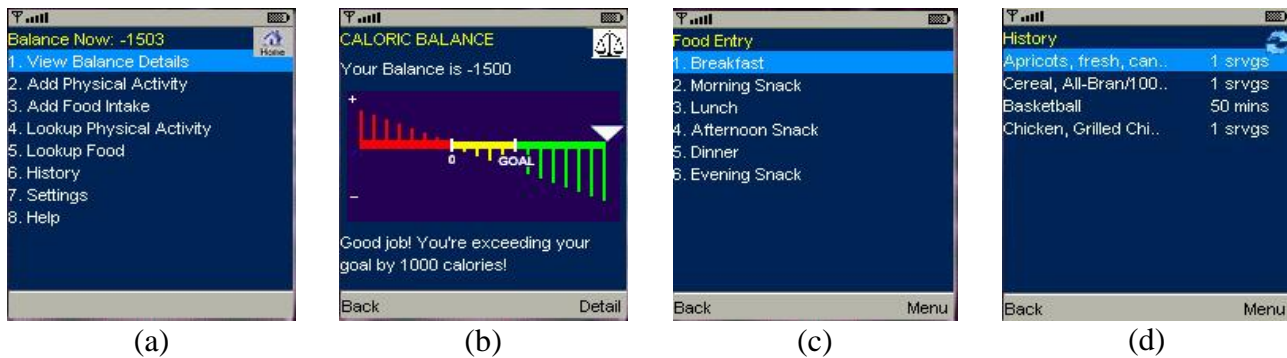
Figure 2 – Screenshots of the PmEB mobile phone client. (a) is the main application menu. (b) is the current caloric balance page. (c) is the meal selection page. (d) is the history page.

activity database, and to keep a record of the users' daily calorie data. This delocalized approach to saving data on a separate location provides for increased storage capacity (than offered by the cell phone's limited memory) and enables more sophisticated methods for displaying and analyzing of data than the phone can support. A web-based interface to the server collects and analyzes the data (e.g. how many calories have I consumed on average for the past n days?)

Our database is comprised of calorie amounts for 750 foods and calorie expenditure estimates for 37 physical activities, including values for different intensity levels. Information in the database is sent and stored on the cell phone client during the application setup.

Web-Based Setup

The web-based setup is used to personalize and automate the calculation of caloric balance based on the following equation:

Caloric Balance = Caloric Intake – Caloric Expenditure – Resting Metabolic Rate

Since resting metabolic rate and caloric expenditure vary from individual to individual, they need to be calculated for each user. The user's resting metabolic rate was calculated using the Harris-Benedict equation [10]. Calories expended from physical activity are also personalized by converting metabolic equivalents for activities to calories expended per minute (cal/min) based on body weight, across varying intensities (vigorous, moderate, mild). To streamline the task of recording behavior, the setup application is used to personalize the mobile client. For physical activities, the user is asked to identify locations where they might be physically active (e.g. Home, Workplace, Gym), and what possible activities they might perform at each location. For food intake, the user is asked what foods and beverages they commonly consume at each meal, including snacks.

Mobile Phone Client

The mobile phone client supports the ability to view current caloric balance, enter calorie intake and expenditure, lookup food and activity information, see a history of past entries, and set the time for daily reminder prompts (Figure 2a). Current **caloric balance is given as a sum of calorie counts for diet, activity and resting metabolic rate (RMR)** (Figure 2b). Lists of food items are categorized by six meal types to facilitate navigation—breakfast, morning snack, lunch, afternoon snack, dinner, and evening snack (Figure 2c). To add food intake, users first select the meal type and then select a food from the associated food list. These automated meal "cheat sheets" are specified by the user during the web-based setup process, but they can be modified on the phone at any time. To add a food not in the cheat sheet, users can either search for the food or select the food item from a comprehensive list of foods by selecting the "more foods" option. Number of servings is entered after food selection. Entering in a physical activity is a similar process, with physical activities categorized by user-designated locations during set-up. An option to manually enter a calorie intake and expenditure amount is available in case the food or activity is not in our database. Users may also enter a step count and have it be converted to a calorie amount (for use with pedometers). The history page shows all entries that were made that day (Figure 2d). All entries are logged with a timestamp.

4. A Four-Phase Pilot Study Design

We conducted our study in four phases. In the first phase, we sought to improve the usability of PmEB based on the usability literature. In Phase 2, we conducted an in-lab user study with six domain experts in behavior informatics. Then in Phase 3, we conducted a user study with six participants that included a week-long deployment. Finally, in Phase 4 we conducted a feasibility study with fifteen participants that included a

month-long deployment. Each phase in our design builds on the findings of the previous, evaluating progressively more complex human-computer interactions. The application was reprogrammed following each phase.

The first three phases guided the usability development of the mobile client application. In this paper, key findings have been summarized and will be explored in detail in a separate work-in-progress paper.

Phase 1: Applying User Interface Design Guidelines

We developed a set of user interface design guidelines adapted from previous work [19], [12], [13], [6], and used them to evaluate our prototype. The set of guidelines consisted of twenty-four criteria, including participant training (should be simple and intuitive, maximum 5 minutes), universal suitability (should be suitable to all types of potential users), and quality of style of interface (should design for person likely to find system most challenging). *Findings. We identified several areas for improvement in the PmEB and made modifications that included creating "HELP" files for reference, a "BACK" option that allows users to undo a step, and a "SAVE" button to confirm entries.*

Phase 2: Heuristic Usability Testing.

We conducted an in-lab evaluation of our prototype with six domain experts in behavioral informatics not previously exposed to PmEB. Our evaluation combined heuristic usability testing [12] with task-based scenarios [17]. In individual one hour sessions, they were given ten functions to perform on PmEB. Examples include checking balance details, entering a new breakfast, and entering a new physical activity. They were instructed to perform a cognitive walkthrough, speaking out loud about positive and negative experiences as they performed the tasks. We recorded all comments and measured the time it took for each task. Afterwards, a group debriefing was performed where participants were asked about their comments on ten usability heuristics [12]. *Findings. We identified several heuristics requiring attention. Program modifications included creating a "HISTORY" function to view and edit the day's entries, improving users' awareness of their location in the application, creating a function that allows users to update the frequent foods and activities lists, and improving the search algorithm for non-frequent foods.*

Phase 3: Ubiquitous Computing Testing.

Usability data was collected from our target user group. We conducted a week-long deployment of PmEB with six users who were clinically overweight or obese (Age $\geq$ 18, BMI $\geq$ 25). Participants were recruited by word of mouth through friends and family. Usability data was gathered using questionnaires and interviews at the end of the trial. Our questionnaire was focused on testing ubiquitous computing usability concepts [15]. We operationalized these concepts into thirteen questions, including: Attention (How many times a day did you use the application?), Trust (Are you aware of security measures?), Conceptual model (Did the application behave as expected?), Interaction (How disruptive and frustrating was the application?), Invisibility (How accurate and customizable was the application?), and Impact (How comfortable were you in using the application in social settings?). Responses were chosen from a Likert scale of 1-5. The exit interview took about an hour. *Findings. Modifications from this phase included fixing application bugs, improving the manual and training procedures, and revising the food database and "HISTORY" function.*

Phase 4: Feasibility Testing.

We conducted a month-long feasibility study with 15 participants who were clinically overweight or obese (age $\geq$ 18, BMI $\geq$ 25). Five participants were randomized into each of three groups: 1) Traditional paper and pen calorie tracking group (Paper Group), 2) Cell phone group using PmEB programmed to prompt one time daily for data collection (One-Prompt Group), and 3) Cell phone group using PmEB programmed to prompt three times daily for data collection (Three-Prompt Group).

Both feasibility and usability were evaluated. Feasibility was evaluated based on 1) compliance with data entry and 2) satisfaction. For the Cell Phone groups, compliance was measured by analyzing data entry on the cell phones that was sent wirelessly to the PmEB server (see section 3).

For the Paper Group, compliance with data entry was obtained from paper caloric tracking forms. These forms were created for this study, and allowed for similar functions as the PmEB application including time of entry, location/meal, activity/food, minutes/servings, total calories expended/consumed, and daily caloric balance. The Paper group also received a paper-based food and physical activity calorie reference. Like PmEB, daily caloric balance was tailored to the individual by having resting metabolic rate calculated for them at intake, and printing the physical activity calorie reference with calories/minute calculated for them.

For all three groups, satisfaction was evaluated by a post-test questionnaire.

The same ubiquitous computing questionnaire from Phase 3 was also given after the field test to compare final usability between groups. The initial setup interview lasted half an hour, while the exit interview lasted about an hour.

Participant Profiles. Fifteen participants were recruited by fliers and emails to listserves from three local universities. The study sample had an average age of 30.4(range 18-51). Nine were women, 13 were White or

Variable	One-Prompt	Three-Prompt	Paper	Overall
Attention:				
Times per Day using the app, mean (sd)	6.0 (5.02)	3.0 (1.10)	5.5 (5.55)	4.79 (4.47)
Trust:				
Aware Security Measures (Y/N), % Yes, n	0, 0	60, 3	25, 1	
Feel Info was Private (Y/N), % Yes, n	60, 3	80, 4	25, 1	
Security and Privacy Important (Y/N), % Yes, n	20, 1	60, 3	0, 0	
Conceptual Model:				
Behave as Expected (1-5), mean (sd)	3.4 (1.14)	3.4 (0.89)	4.8 (0.50)	3.8 (1.05)
Function as Expected (1-5), mean (sd)	3.8 (1.30)	3.4 (0.89)	4.5 (0.58)	3.9 (1.03)
Interaction:				
Disrupting (1-5, lower is better), mean (sd)	1.2 (0.84)	2.0 (1.41)	2.8 (1.26)	1.9 (1.27)
Frustrating (1-5, lower is better), mean (sd)	1.0 (0.71)	2.0 (1.58)	2.3 (0.96)	1.7 (1.20)
Invisibility:				
Understand Key Functions (1-5), mean (sd)	4.4 (0.55)	4.2 (0.84)	5.0 (0.0)	4.5 (0.65)
Perform all Functions (1-5), mean (sd)	4.0 (0.71)	4.0 (0.0)	4.0 (1.41)	4.0 (0.78)
Accuracy (1-5), mean (sd)	3.0 (0.71)	3.4 (1.34)	3.0 (1.63)	3.1 (1.17)
Customizable (1-5), mean (sd)	3.2 (0.45)	4.2 (0.84)	2.8 (1.50)	3.43 (1.05
Impact:				
Comfort in Social Settings (1-5), mean (sd)	4.2 (1.79)	3.8 (0.84)	3.0 (1.41)	3.7 (1.38)
Change Activity or Eating habits (Y/N), % Yes, n	100, 5	80, 4	75, 3	
Motivating (Y/N), % Yes, n	80, 4	100, 5	75, 3	
Learn or Increase Knowledge (Y/N) , % Yes, n	80, 4	80, 4	100, 4	
Awareness of Activity and Eating habits (Y/N), % Yes, n	100, 5	80, 4	75, 3	
Confidence in Improving (Y/N), % Yes, n	60, 3	60, 3	25, 1	
Interact with Environment (Y/N), % Yes, n	40, 2	80, 4	50, 2	

Table 1. Ubiquitous Computing Usability Evaluation following the Field Study

Asian/Pacific Islanders and two Hispanic. Fourteen participants were either in college or completed college. The Three Prompt Group members differed from the other participants in that they tended to be older (average age 35.6), married (4 out of 5), hold graduate degrees (4 out of 5), make high incomes (4 out of 5 making between $75,000-$99,999), and employed as professionals/managers/administrators (4 out of 5).

More than half of the participants (8 out of 15) have used cell phones for over 5 years, and 6 out of 15 used cell phones over 11 times a day for personal use. All 15 agreed that a mobile caloric energy tracking application would be helpful, and 13 indicated they enjoy using hi-tech products.

5. Key Findings

Results from our feasibility study were based on two key assessments compared among all study groups: 1) a ubiquitous computing evaluation, 2) a feasibility evaluation assessing compliance and satisfaction. For each assessment, quantitative measures are presented first, followed by qualitative data in the form of a thematic analysis.

Ubiquitous Computing Evaluation:

The ubiquitous computing evaluation focused on the following usability concepts: attention, trust, conceptual model, interaction, invisibility and impact. All responses were given on a Likert scale from 1-5.

Table 1 presents findings from the usability evaluation survey by study group. One of the Paper Group participants did not complete the survey. While none of the tests reached statistical significance by Chi-squared and ANOVA analysis, the descriptive data provides useful information.

Attention: Overall participants used either cell phone or paper tracking 4.79 times a day, with similar values between groups.

Trust: Results were mixed for awareness of security measures between the groups, but cell phone users felt their information was more private (60% and 80% vs. 25%). More cell phone users also felt security and privacy was important.

Conceptual Model: Paper Group members felt their forms behaved (4.8) and functioned (4.5) as expected. The One Prompt Group (3.4, 3.8) and Three Prompt Group (3.4, 3.4) members gave PmEB lower scores. Cell Phone Group members giving the lowest score felt function suffered because of the limited food database and serving size entry options.

Interaction: The lower the score from 1-5, the better. In this concept, the cell phone group received better marks. The One Prompt Group felt PmEB was neither disruptive (1.2) nor frustrating to use (1.0). Average scores for the Three Prompt Group were also low (2.0, 2.0). Paper Group average scores were worse (2.8, 2.3).

Invisibility: All three groups felt similarly about understanding and performing all functions. Perceived
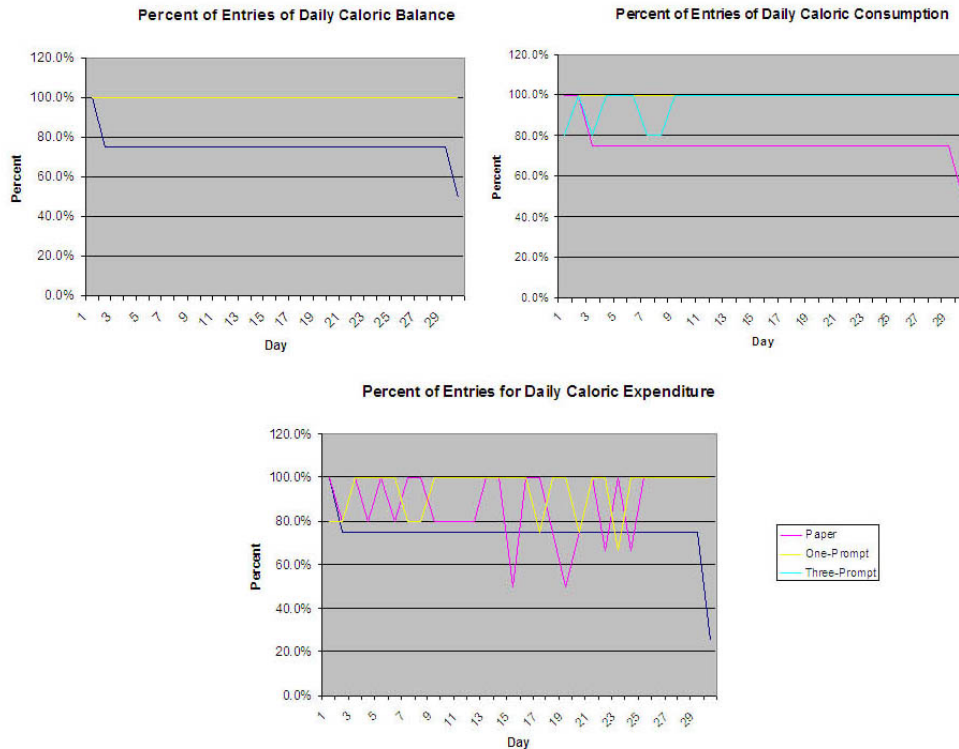
Figure 3 – Percent of entries made for daily caloric balance, consumption, and expenditure among the three groups.

accuracy was low for all groups, with an average of 3.1 overall. The Cell Phone Groups gave PmEB slightly higher scores for customizability (3.2 and 4.2 vs. 2.8).

Impact: The Cell Phone groups scored higher on most measures in this concept, including comfort in social settings, changing physical activity or eating habits, motivating, increasing awareness of physical activity and eating habits, and confidence in improving behavior. The Three Prompt group had higher scores for increasing interaction with the environment (80% vs. 40% and 50 %). The Paper group scored higher on helping users learn or increase knowledge about healthy behaviors.

Feasibility Evaluation:

The feasibility data was based on assessments of compliance and satisfaction.

Compliance. Compliance with the entry of daily caloric consumption, expenditure, and balance was compared among the three groups. First, **compliance aggregated** over the entire month was calculated for entry of daily caloric consumption, expenditure, and balance. Compliance was calculated as the percentage of actual versus total possible entries. Except for one Paper Group member with low compliance (7%), the compliance rates across participants in all three groups for entry of *daily caloric consumption* (Figure 3) were high, ranging from 72% to 100%. Compliance with entry of *daily caloric*

expenditure (Figure 3) was also high across participants (81.8-100%) with a couple of exceptions: the same Paper Group Member only totaled his entries once (3.3%), and a One Prompt Group member had a low compliance of 50%. Similarly, compliance with entry of *daily caloric balance* (Figure 3) was very high (96.7-100%) with the same Paper Group member exception (3.3%).

Second, the **change in compliance** during the month was also examined, to explore whether compliance rates decreased over time. The graphs below indicate the percentage of participants in each group with entries for that day. For example, on Day 1 of the study, 100% of One Prompt members (5 out of 5) and Paper Group members (4 out of 4) entered Daily Caloric Consumption. Only 80% of Three Prompt members (4 out of 5) made entries that day.

In summary, across the three categories of data entered, on average the PmEB Groups maintained higher levels of compliance than the Paper Group.

Satisfaction. Satisfaction was analyzed based on a questionnaire that explored how helpful PmEB or paper tracking was, the frequency and duration of interactions, whether participants would recommend their intervention, and how their intervention compared with previous weight management experiences. Table 2 presents findings from the satisfaction evaluation survey by study group.

	Mean (SD)			
Variable	One-Prompt	Three-Prompt	Paper	Overall
Helpfulness of Intervention for:				
Monitoring Caloric Balance (1-4)	4.0 (0.0)	3.4 (0.89)	3.25 (0.96)	3.57 (0.76)
Learning Activity Expenditures (1-4)	3.6 (0.55)	3.0 (0.71)	4 (0.0)	3.5 (0.65)
Learning Food Intake (1-4)	3.8 (0.45)	3.6 (0.89)	4 (0.0)	3.79 (0.58)
Helpfulness of Cell Phone Functions:				
Prompts (1-4)	1.4 (0.5)	3.2 (0.84)	N/A	2.3 (1.16)
Message (1-4)	2.0 (1.41)	3.4 (0.89)	N/A	2.7 (1.34)
Frequency and Duration of Interactions:				
Use Times per Day (1-10)	5.2 (3.27)	3.6 (1.34)	4.0 (4.08)	4.3 (2.87)
Minutes per Session (minutes)	4.6 (3.13)	6.2 (2.39)	3.5 (1.29)	4.9 (2.54)
Agreement with Following Statements:				
Easy to navigate (1-3)	3 (0.0)	2.4 (0.49)	2.75 (0.43)	2.71 (0.45)
Enjoyable (1-3)	2.4 (0.8)	2.8 (0.4)	2 (0.71)	2.43 (0.73)
Teach new Info (1-3)	2.6 (0.49)	2.6 (0.49)	2.75 (0.43)	2.64 (0.48)
Motivating (1-3)	2.8 (0.4)	2.8 (0.4)	2.5 (0.87)	2.71 (0.59)
Change Eating Habits (1-3)	3 (0.0)	2.8 (0.4)	2.5 (0.5)	2.79 (0.41)
Change Physical Activity (1-3)	2.8 (0.4)	2.0 (0.63)	2.5 (0.83)	2.36 (0.72)
Recommend:				
Recommend to friends/family (Y/N), % Yes, n	100, 5	100, 5	75, 3	
Comparison w/ Past Weight Loss Attempts:				
Easy to use (1-3)	3.0 (0.0)	2.33 (0.47)	2.0 (1.0)	2.45 (0.78)
Convenience (1-3)	3.0 (0.0)	3.0 (0.0)	1.5 (0.5)	2.45 (0.78)
Teaching new info (1-3)	2.25 (0.43)	2.33 (0.94)	3.0 (0.)	2.55 (0.66)
Motivating (1-3)	2.5 (0.5)	2.67 (0.47)	2.0 (0.71)	2.36 (0.64)
Change Eating Habits (1-3)	2.75 (0.43)	2.0 (0.82)	2.25 (0.83)	2.36 (0.77)
Change Physical Activity (1-3)	2.5 (0.5)	2.33 (0.94)	2 (0.71)	2.27 (0.75)

Table 2 – Satisfaction measures between the three groups.

While tests did not reach statistical significance, comparing average scores provided useful information. Cell Phone Groups gave higher scores for PmEB as helpful in calculating caloric balance (4.0, 3.4, vs. 3.25 for the Paper Group). However, as with the usability test, the Paper Group gave higher scores for how helpful their paper-based materials were for learning activity expenditures and food intake. The Three Prompt Group felt that the prompts (3.2) and messages (3.4) were somewhat helpful, whereas the One Prompt Group gave even lower scores (1.4, 2.0).

While all groups used their interventions about the same number of times a day, Cell Phone Group sessions tended to last longer (4.6 and 6.2 minutes vs. 3.5 minutes). Cell Phone Group members didn't mind, as more strongly agreed that PmEB was enjoyable, motivating, and changed their eating habits than did the Paper Group. Again, Paper Group Members more strongly agreed that their paper forms taught new information.

All groups recommend their intervention to family and friends, though the Cell Phone Groups members were unanimous. When compared to previous weight loss attempts, the Cell Phone Groups felt PmEB averaged a rating of "better" for all categories except for "Changing eating habits," where it was "same" or "better." Across categories, the Paper Group averaged a rating of "same as" compared to previous attempts for most categories. Scores for the Cell Phone Groups exceeded those for the Paper Group except in two categories: "Teaching new information" (Paper Group had highest score) and "Changing eating habits" (Paper Group score was in between Cell Phone Groups).

In summary, satisfaction scores from the Cell Phone Group members generally compared favorably against both the Paper Group and past weight management attempts.

Thematic Analysis:

Several themes emerged from our qualitative analysis of the participant interviews gathered during the feasibility study:

- Self-monitoring increased awareness in all groups.
- Paper diaries are very *inconvenient*, leading to recall bias and lower compliance.
- PmEB users found it to be very *convenient* and *easy to use*.
- PmEB *motivated* users in a variety of ways.
- PmEB users developed *emergent weight management practices*.
- PmEB users found *food entry challenging*.
- PmEB users *disliked the prompts*.

Self-monitoring increased awareness in both groups. Several became aware of the ***larger than expected amounts of calories consumed***, as exemplified by this quote: *"It made me aware of the calories I was consuming and how high in calories some foods were."* Others became aware of ***where and when they would eat***

poorly or well: *"(I became aware of) the times that I tend to overeat: social occasions & eating in restaurants; and the times that I control the intake the best: at work where there are few options to purchase food and at home where I have control over what food is bought and brought into my home."* Still others became **aware of nutritious foods**: *"I became aware of some good foods with low calories that I could always fall back on."* Many developed the habit of looking at **nutritional labels**: *"I look at nutrition labels more than I used to", "By reading labels I switch from Gatorade to flavored water and reduce my fast food intake."*

Paper diaries are very inconvenient, leading to recall bias and lower compliance. The Inconvenience of the paper diaries led Paper Group members to develop alternative data entry behaviors, increasing the likelihood of recall bias. Several Paper Group users resorted to other **alternate recording methods** to avoid bringing around the paper materials. A typical response was: *"I used my own smaller diary to carry around everyday and transferred the info about once a week to the paper diary for the study."* Other people relied on **memory**: *"I didn't often use the diary itself in 'social settings'; rather, I filled it out in the evening after returning home. My submission would have been much more accurate had I done that."* Some paper diary users tied the inconvenience to the **lower compliance** that we measured: *"The paper technique is probably only useful for short periods - such as 1 week or less. After 1 week, it becomes too burdensome."* Though they had never seen PmEB, several paper users were excited about the possibilities of a cell phone application: *"I would like to see how the cell phone technology works. The paper technique is very cumbersome to use"* and *"If the cell phone technology is easy to use and works well, I would highly recommend it as a useful learning and tracking tool."* Thus, inconvenience had a powerful effect, possibly explaining lower compliance and satisfaction. While we expected some users to rely on memory, we did not count on users developing their own recording instruments. Nor did we expect users to "recommend" the cell phone application. Such comments were absent from cell phone users.

PmEB users found it to be very convenient and easy to use. Typical comments included: *"It's a convenient tool for people who are interested in their daily caloric intake/balance. One doesn't need to refer to a table/chart all the time," "Cellular phone data recording is definitely more convenient than the paper-based that I've done before,"* and *"It's a very easy to use program that doesn't take up any extra room (stored in a phone) and it makes you very conscious of your caloric balance."* There were numerous comments about PmEB's value for **self-monitoring** and increasing **awareness**. For example: *"It's*

a great way to monitor yourself. It is hard to gauge how much you eat sometimes and this program helps quantify it," "easy to use and eye opening,"* and even *"I loved it. It was really fun to monitor myself.."* Finally, some general effusive comments: *"I wish that I didn't have to give it up! I really enjoyed using it!"* and *"Love to try it again!"* Convenience may help explain higher compliance and satisfaction for PmEB users, supporting our usability development. PmEB appears to be a very promising EMI tool, as people considered it fun and enjoyable to monitor themselves.

PmEB motivated users in a variety of ways. Knowing a tangible number of **calories expended** for a physical activity was motivating: *"Providing a caloric number for activities made it easier to motivate myself to exercise."* Another user ties calories expended to positive reinforcement: *"I also felt very good after the gym since I could input my calories burned into the program. It was great for positive reinforcement."* **Prompts** shown after each activity or food entry were motivating: *"The progress prompt made me wanted to work out more and increase my steps. It also showed which foods hurt the caloric intake count."* The "Balance Details" motivated others. One person was motivated by the **tailored messages**: *"it motivated me when the monitor said that I was gaining weight. I tried to make it up by doing more activities."* Another was motivated by the **colors** used: *"seeing your daily calories in the RED was very unsettling, makes you go out and run."* Interestingly, the general response to caloric imbalance, was motivation to increase physical activity, not decrease food intake.

PmEB users developed emergent weight management practices. Cell Phone users used PmEB for **planning, decision support, setting minimum activity levels**, and **pacing caloric intake and expenditure** throughout the day. One user describing using PmEB for planning: *"When I realized how much I have eaten the previous day, I'd tend to lower my calorie intake on the following day."* Here is an example of PmEB as decision support: *"I would realize that I already reached caloric count for the day, so I would know I'd had enough. Also, if I went over my cal. I would want to go to the gym to make up for it."* Another user said: *"I watch what I ate and it forced me to set a minimum number of steps I took a day."* One user kept balance throughout the day by pacing: *"It helped me to pace my caloric intake and also how bad I was during the bad times. the reminders of "your gaining weight" was good pressure. I rather have it from the phone rather a person."*

PmEB users found food entry challenging. This continuing challenge is due to several factors – a **food database that isn't comprehensive** due to limited device

memory, *inadequate food search algorithms*, *inability to add food items* directly, and *inability to add fractions of serving sizes*. The following comments for Cell Phone Group members were typical: *"I had hoped to have more information on different foods, especially at restaurants. A larger database would have helped the most. I had to go to the internet for caloric content," "I wish you could add food entries to the food list," "(I would have liked a) larger food selection, ability to choose the serving size, ability to change your caloric deficit goal (i.e.- instead of -500 calories, shoot for -1000 calories), ability to enter fiber, fat, salt, etc.,"* and *"the minimal amounts were sometimes too much."* No comments were directed towards problems in entering physical activity.

PmEB users disliked the prompts. Methods of Intervention still require significant investigation. Cell Phone users from both groups felt that after they got into the habit of entering data, they no longer needed prompts: *"I didn't really need the prompts, as I had gotten into the habit of immediately recording food intake or exercise,"* and *"The phone was generally prompt enough. It was a little annoying to have to open the text message to turn of the alarm."* Prompts were particularly disruptive for people with irregular schedules: *"I have a very "fluid" schedule, sometimes I'll be up until 4 in the morning and sometimes I'll go to sleep at around 12 so the prompts to update were not that helpful, what worked for me was just remembering that I had to input data into the application."* Intervening appropriately still requires significant investigation.

6. Discussion and Future Work

Our overall goal is to develop an EMI application for obesity, performing assessments and providing intervention where and when appropriate. This application must perform better than the current most common "ubiquitous" method – paper-based tracking. Our application had to overcome the limitations of paper for self-monitoring, namely low compliance, recall bias, and labor-intensiveness. With our pilot study of PmEB, we were able to achieve higher compliance than paper diaries. Though duration of interactions seemed to be longer with PmEB than paper diaries, users were more satisfied and enjoyed using it. While we did not test recall bias directly, Paper Group members reported using alternate tracking devices and memory while PmEB users did not, introducing potential sources of inaccuracy. PmEB appears to be a good prototype EMI application for addressing weight management.

To make this progress toward our goal, we needed to specify a research and development methodology that emphasizes usability to achieve convenience and compliance. Incorporating design guidelines and input from domain experts and target users allowed us to create a convenient, easy to use application, which in turn increased both compliance and satisfaction significantly.

New areas of inquiry identified in this study include exploring emergent health behaviors in response to ubiquitous computing health applications, refining sources of motivation, improving food entry, and exploring effective methods of ecological intervention. We will also be refining our four-phase methodology through larger-scale feasibility and validation studies. We will continue our efforts to apply new mobile technologies to these issues to contribute to solutions for obesity.

7. Conclusion

We applied a four-phase research and development methodology to pilot test our PmEB mobile phone application for monitoring real-time caloric balance. When compared to paper and pencil we found that the mobile phone users scored PmEB the same as or higher on usability, compliance and satisfaction, showing that PmEB is feasible. Our thematic analysis supports these results and suggested areas of improvement.

8. Acknowledgements

9. References

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