

Using Context to Reveal Factors that Affect Physical Activity

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There are many physical activity awareness systems available in today's market. These systems show physical activity information (e.g., step counts, energy expenditure, heart rate) which is sufficient for many self-knowledge needs, but information about the factors that affect physical activity may be needed for deeper self-reflection and increased self-knowledge. We explored the use of contextual information, such as events, places, and people, to support reflection on the factors that affect physical activity. We present three findings from our studies. First, users make associations between physical activity and contextual information that help them become aware of factors that affect their physical activity. Second, reflecting on physical activity and context can increase people's awareness of opportunities for physical activity. Lastly, automated tracking of physical activity and contextual information benefits long-term reflection, but may have detrimental effects on immediate awareness.

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1. INTRODUCTION

People use personal informatics systems to inform them of their behavior, but people might better understand their situation and improve or change their behavior if these systems also allowed people to see the factors that affect their behavior. However, most personal informatics systems only track one type of behavioral information, so people have to depend on their memory to know and understand the effect of different factors on their behavior. A solution is to use contextual information, which may represent factors that affect behavior. For example, contextual information, such as location, activities, and people, may reveal factors that affect physical activity. However, there are several open questions regarding the use of contextual information to inform people of factors that affect their behavior.

—How do systems appropriately support the collection and reflection on contextual and behavioral information?

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- How effective is contextual information in informing people of factors that affect their behavior?
- How do people use contextual information to learn/understand the factors that affect their behavior?
- Would this new awareness lead to changes in behavior?

One type of behavior that may benefit from awareness of contextual information is physical activity. There are several reasons to explore the domain of physical activity. First, physical activity is a behavior that can make a big impact on health by lowering the risk of preventable diseases, such as obesity, chronic heart disease, diabetes, and high blood pressure [Pate et al. 1995]. Second, physical activity is affected by many factors, such as lack of time, choice of activities, the environment, and social influence [Sallis and Hovell 1990]. These factors could be inferred from contextual information, such as activity and location information. Lastly, there are many personal informatics tools for physical activity and more people are using them [Fox 2011], but not many systems support reflecting on physical activity information along with contextual information.

In this article, we present our work in starting to explore the use of contextual information in personal informatics systems within the domain of physical activity. We started with a diary study, then we developed two prototypes, *IMPACT* 1.0 and 2.0, which supported collection of and reflection on physical activity and contextual information. The two prototypes differed in how they supported collection of information: *IMPACT* 1.0 was manual (participants recorded on paper booklets), while *IMPACT* 2.0 was semi-automated (participants used mobile phones). We deployed the prototypes in a series of field studies that explored the value of contextual information in revealing factors that affect physical activity. We employed iterative, user-centered human-computer interaction methodologies and took the lessons we learned from each iteration to improve the next.

These field studies provide some evidence that contextual information can help participants become more aware of the factors that affect their physical activity. However, we also found that the awareness of factors is dependent on how the prototypes supported collection of physical activity and contextual information. When collection was manual, participants were more aware of factors because they were more engaged with their data; they had to observe their behavior, record data on a booklet, and transcribe the data on the Web site. On the other hand, when collection was semi-automated, participants who collected contextual information were not more aware of factors compared with other participants who did not collect contextual information. These participants may have been less engaged with their data because the mobile phone was responsible for collecting most of the data. While the manual prototype improved awareness of factors, the benefit came with a cost: participants reported that recording data manually was burdensome, which may lead to lower usage levels over a long period of time. On the other hand, participants who used the semi-automated prototype found the system easy to use. This suggests that they are more likely to record data over a long period of time. Thus, they are more likely to have the necessary data to reflect on a wider range of time.

In the following sections, we describe a scenario to illustrate concepts relevant to this research. Next, we discuss related work in physical activity awareness and research in self-monitoring, self-tracking, and personal informatics. We outline the general approach that guided our studies. We describe the studies and the prototypes we created and identify problems that people experienced monitoring both physical activity and contextual information. We explain the lessons we learned and how they led to each subsequent prototype and study. Finally, we discuss the implications of these lessons

and make recommendations on the design of personal informatics systems that integrate contextual information to help people gain more self-knowledge.

2. SCENARIO

To illustrate how contextual information might help with understanding factors that affect physical activity, we present the following scenario.

Alice was a new student in college. After a few months as a freshman, she noticed that she gained some weight, a common phenomenon called the “freshman fifteen.” This worried her because her family has a history of heart disease. To resolve this problem, she decided to track her physical activity to find opportunities when she could be more active. She used a Fitbit pedometer to track her step counts. After a month of collecting data, she looked at a graph of her step counts and noticed several days of inactivity and a few days of greater activity. She asked herself: What was she doing during those days? Where was she spending her time? Who was she spending time with? She could not remember everything that she did in the past month, so she could not answer her questions for all the days. Contextual information, such as her activities, location, and people, could help her answer these questions. Alice did not consider collecting contextual information related to her physical activity, but if she wanted to, how could a system support her? Would it help her identify the factors that affected her physical activity? Alice did not have the right tools to support collection of contextual information. But if she did, we believe contextual information could have helped Alice identify the factors that affected her physical activity.

This scenario highlights several issues with tracking contextual information with physical activity. First, most physical activity awareness systems only measure physical activity levels, such as pedometers, FitBit, and Nike+iPod. While most physical activity awareness systems only measure physical activity levels, physical activity levels are not the only information relevant to physical activity; information about factors that affect physical activity are also important. Physical activity is affected by lack of time, choice of activities, the environment, and social influence [Sallis and Hovell 1990]. Awareness of these factors is critical to circumventing barriers to becoming active [Centers for Disease Control and Prevention 2008] and may help with finding active lifestyle activities that have been shown easier to incorporate into daily life, (e.g., walking versus driving short distances or taking stairs versus elevators) [Levine et al. 2006; Pate et al. 1995]. Focusing only on physical activity levels leaves a gap in understanding the behavior and what causes the behavior. For example, diabetes patients are taught to be aware of their blood sugar level, but blood sugar levels alone do not reveal the behaviors that contribute to those levels [Frost and Smith 2003; Mamykina et al. 2006]. People need information in addition to physical activity levels to help them understand how different aspects of their lives affect their physical activity.

There is little support for people interested in the factors that affect their behavior; they have to use an ad hoc collection of Web sites and devices to collect data. The responsibility lies on them to put together the pieces of their personal data puzzle. People have to go through the tedium of organizing, formatting, and integrating their data together. Worse, they are left to remember, infer, or guess how the different factors affect their behavior. How can a personal informatics system appropriately support people in tracking and reflecting on the factors that affect their behavior?

One source of information that users can use to find the factors that affect their behavior is contextual information. According to Dey [2000], “Context is any information that can be used to characterize the situation of an entity.” In the case of personal informatics, the *entity* is the individual and the *situation* is some behavior about an aspect of a person’s life, while context *characterizes* the individual’s behavior, some of which may be factors that have a direct effect on the behavior. For example, events

Table I. Overview of Commercial Products and Research Activities in Physical Activity Awareness

Name	Monitoring Device	Information monitored	Feedback	Social
Pedometer	Pedometer	Aggregate step counts	Device	No
Nokia 5500 SportsTracker Shakra [18]	Mobile phone	Aggregate step counts	Device	No
UbiFit Garden [5]	Mobile phone	Duration of different activities	Device	No
	Mobile phone & Intel MSP	Duration of different activities	Device	No
Fish'n'Steps [17]	Pedometer	Aggregate step counts	Device & public display	Public display
BodyMedia SenseWear	SenseWear armband	Time-stamped activity level	Desktop application	No
Nike+iPod	iPod and in-shoe device	Distance walked/ran	Device & web site	Share in web site
First IMPACT prototype	Pedometer & journal	Step counts & context (manual)	Device & web site	No
Second IMPACT prototype	Mobile phone and GPS	Time-stamped step counts & context	Device & web site	No

attended may have an effect on one's productivity or people one spent time with may have an effect on one's moods. Can contextual information in personal informatics systems reveal factors that affect behavior?

We are missing an opportunity here! Mobile phones are increasingly able to collect contextual information. There is plenty of research on how to capture contextual information. Using contextual information will become easier to incorporate into physical activity awareness systems. How useful could they be? What can they offer beyond awareness of physical activity levels? Could they actually help people become aware of factors that affect their behavior? What are the challenges?

3. RELATED WORK

We have organized the related work into two categories: physical activity monitoring and integrating context. Table I provides an overview of several commercial products and research activities in the domain of monitoring physical activity. We also present research that hints at what role contextual information may play in monitoring physical activity.

3.1. Physical Activity Awareness

In this section, we explain why we picked physical activity awareness as a domain to explore the use of contextual information in a personal informatics system. We provide an overview of existing physical activity awareness systems (Table I). We also present research that hints at what role contextual information may play in monitoring physical activity.

Lack of physical activity is a common problem that increases the risk of otherwise preventable diseases, such as obesity, chronic heart disease, diabetes, and high blood pressure [Pate et al. 1995]. A recent study by the Center for Disease Control found that more than half the adult U.S. population did not participate in regular physical activity [Kruger and Kohl 2008]. People try to increase their physical activity, but many return to sedentary habits [Dishman et al. 1980].

Lack of awareness of physical activity is one of the reasons people lead sedentary lifestyles [Centers for Disease Control and Prevention 2008]. Physical activity awareness systems collect physical activity information to help people become aware of their physical activity levels, such as step counts, energy expenditure, and heart rate. Pedometers have been shown to also help increase physical activity [Bravata et al. 2007;

Rooney et al. 2003; Tudor-Locke et al. 2004]. There is also research on novel visualizations for physical activity awareness. UbiFit Garden [Consolvo et al. 2008] displayed physical activity levels using a garden metaphor in a glanceable display on a cell phone. The Shakra system used GSM signal strength to detect time spent engaged in physical activity and displayed cartoon visualizations of activity on a mobile phone [Maitland et al. 2006]. Fish n' Steps motivated physical activity by using visualizations of fish in a tank [Lin et al. 2006].

3.2. Personal Informatics

Individuals have been tracking data about themselves for a long time. Benjamin Franklin tracked whether he broke one of his 13 virtues every day [Franklin 1916]. Artists [Harrison et al. 2005] and designers (e.g., Nicholas Felton's Feltron Annual Report 2005–2010, <http://feltron.com>) have also explored self-tracking. Gordon Bell, computer engineer, is the experimental subject of the MyLifeBits project [Gemmell et al. 2006], which uses various computing technologies to collect many types of behavioral information. These people are successful at collecting data because they are either very motivated or they have access to technology to facilitate data collection. Personal informatics systems are emerging to help regular people collect and reflect on information about themselves to become more aware of different aspects of their lives. Knowing oneself has been shown to foster self-insight [Hixon and Swann 1993], to increase self-control [O'Donoghue and Rabin 2001], and to promote positive behaviors, such as energy conservation [Seligman and Delay 1977].

Pedometers and other physical activity awareness systems belong to a class of systems called *personal informatics*. Personal informatics systems help people collect behavioral information for the purposes of self-reflection and gaining self-knowledge [Li et al. 2010]. Today, there is a personal informatics device, application, or Web site for almost any behavior (see listing at <http://personalinformatics.org/tools/>). Like physical activity awareness systems mentioned earlier, most personal informatics systems only show behavioral information, for example, pedometers count number of steps, diabetes devices measure blood sugar levels, and finance applications track purchases. This may be for simplicity's sake, since collecting only one type of information is easier. The user has to only wear one device or observe one type of information. However, there is evidence that showing factors that affect behavior is beneficial. Frost and Smith [2003] demonstrated that showing photographs of daily food intake and blood sugar levels revealed to users the effect of different types of food on blood sugar. The Affective Diary [Stahl et al. 2009] is a digital diary that combines written notes with information from body sensors and mobile phones, so that users can remember and reflect on their past. Some personal informatics systems do support collecting information about multiple behavioral facets, such as Daytum (<http://daytum.com>), Grafitter (<http://grafitter.com>), and Myrococosm [Assogba and Donath 2009], but users have to look at each of the visualizations separately, which makes it difficult for people to reflect on the information and find associations.

Computing technology can help with this problem. Much ubiquitous computing research has explored the capture, storage, and access of personal information [Abowd and Mynatt 2000]. The community also has performed plenty of research on how to capture different kinds of contextual information [Dey 2000]. Guidelines for designing physical activity awareness devices have been discussed by several projects [Consolvo et al. 2008; Jafarinaiimi et al. 2005] and we leverage these principles in the design of our prototypes. However, we currently do not know how to appropriately incorporate contextual information into personal informatics systems to help in revealing factors that affect behavior.

We can automate data collection enabling people to track more information. However, as we found in our studies, whether the system has automated or manual support for data collection impacts users' awareness of their behavior. This is because using a personal informatics system has to provide user support in several ways. According to the stage-based model of personal informatics systems [Li et al. 2010], there are five stages when using personal informatics systems (in order): *preparation*, *collection*, *integration*, *reflection*, and *action*. The model has four properties: (1) barriers in earlier stages affect later stages; (2) stages are iterative (i.e., can be revisited by users); (3) stages are manual or automated or a combination of both; and (4) systems are uni- or multifaceted (i.e., supported one or more types of information). Of the stages described in the model, this article focuses on the use of contextual information during the collection, integration, and reflection stages. In the preparation stage, we chose the contextual information that users collected (i.e., activity, location, and people), instead of leaving the choice to users. We did not focus on the action stage because we wanted to focus on the issues concerning the earlier stages as issues in these stages may adversely affect the later stages, as suggested by the first property of personal informatics systems. Among the other properties, we explored the benefits of a multifaceted system that allows users to reflect on their physical activity and various types of contextual information. We also created two prototypes: one had a collection stage that was manual, while the other's collection stage was semiautomated.

4. STUDY APPROACH

In this section, we discuss the general approach that guided how we conducted our three studies.

We worked primarily with sedentary people because research suggests that they are less aware of how active they are and they need more information about how to become active compared to active individuals [Sallis and Hovell 1990]. Consequently, we focused on walking as a physical activity because sedentary individuals can more easily integrate walking into their daily lives than other forms of physical activity [Norman and Mills 2004]. We recruited a wide swath of people with different backgrounds within the city proper using various recruiting tools: Craigslist, an experiment recruiting Web site, online newsgroups, and flyers. We screened participants using a prequestionnaire that included the Stages of Behavior Change Items [Marcus et al. 1992] based on Prochaska's Stages of Change Model [Prochaska and DiClemente 1983]. The model describes that people progress through five stages of behavior change: precontemplation (no intention to change), contemplation (intention to change), preparation (prepare to change), action (involved in change), and maintenance (sustain change). All participants in the studies were sedentary, that is, they were identified as being in the first three stages: precontemplation, contemplation, and preparation. For each study, we recruited a different batch of participants because we wanted all participants to have fresh experiences monitoring their physical activity.

While there are many kinds of information that can be added to step counts, we focused on three different kinds of contextual information that have been explored extensively by the ubiquitous computing community: activity, place, and people. As technologies that monitor this information become more robust, they can be more readily integrated into physical activity awareness devices.

We also took a user-centered approach in conducting our studies. We started with the needs of our users and then created a series of prototypes to observe how users reflect on their information. There were three reasons for this. First, the primary goal of the studies was to understand how increasing awareness of context about physical activity affects the user and what the benefits are compared to existing systems before we invest time and money on developing more sophisticated technology. Second, we

wanted to make sure that our deployed technologies were robust enough to be used for a long period of time. Finally, the current state of most systems to track activity and people require wide infrastructure changes or require more devices than most of our users were willing to wear. Our approach is similar to technology probes [Hutchinson et al. 2003], where low-fidelity prototypes are used to observe how people might use a new technology. As we progressed through the studies, we addressed the lessons learned from the earlier trials.

We conducted studies that spanned a long period of time and were in situ for two reasons. First, if reflecting on information about oneself is going to be useful, users will need to have monitored their behavior for an extended amount of time and the data they view needs to be their own data (as opposed to synthetic data or someone else's data). Second, we wanted our studies to be ecologically valid. Consolvo and colleagues [2007] further described the value of in situ deployments for computing technologies.

In the following sections, we describe the three studies that we conducted. Each section is organized in the following manner. First, we explain the motivation for the study. Next, we describe the methods we used in the study and any prototypes we developed. Then, we report how people used information about their physical activity and contextual information. Finally, we discuss the implications of the results and how it guided the next study and prototype iteration.

5. DIARY STUDY (STUDY A)

Before expending time and resources on a prototype application, we wanted to explore how people would reflect on contextual information about their physical activity. Thus, we conducted a diary study [Rieman 1993] where we asked users to record their step counts, activities, location, and people with whom they spent time. The participants' diaries produced a detailed record of contextual information about their step counts, which we asked users to reflect on.

5.1. Method

The study spanned three weeks in which participants carried a paper journal (4.25 in \times 5.5 in) to record their activities. Participants also wore the BodyMedia SenseWear armband (<http://bodymedia.com>), which senses acceleration, galvanic skin response, skin and ambient temperature to calculate calories burned and to count steps. In the first week, participants did not see their physical activity data, since the armband has no display. In the second week, participants also carried a pedometer along with the armband, so that they saw aggregated step counts in real time. We used the Omron HJ-112 Digital Premium Pedometer because it is highly accurate, can be worn comfortably on the waist or carried in a pocket, and is silent as it has no mechanical parts [Consumer Reports 2004]. In the final week, we took away the pedometers and gave participants printouts of daily reports of their physical activity from the desktop application that synchronizes with the armbands. The reports showed graphs of time-stamped step counts for every minute of the day.

Participants used the journal to record every time they changed activities. The journal had fields for time, type of activity, location, and people. At the end of the day, the journal asked participants about their day: unusual events, awareness of activity, and other notes.

We recruited 4 participants who were trying to be physically active (A1–A4, ages 25, 50, 44, and 36, respectively). A1 was a college student, while A2, A3, and A4 worked as staff in various university departments. A2 was married with children, while the rest were single. Participation included 4 audio-taped face-to-face interviews: at the beginning of the study and at the end of each week. We also collected responses from

questionnaires and handwritten notes. Regardless of their step counts, participants received \$ 150 for completing the study.

5.2. Results

Participants had excellent compliance over the three weeks of the study; they recorded at least one activity per hour. Participants liked the detailed daily reports of time-stamped data from the SenseWear armband for reflection. Interviews indicated that this detailed data helped users to better understand the times and days at which they were physically active. They routinely matched segments on the graph with activities they recorded in the journal to better understand how much physical activity they were performing while engaged in different activities. A1 said that the graphs were useful “because I was able to quantify my physical activity” and that she compared “the peaks on the charts to see what I was doing.”

Participants became more aware of their physical activity level and were often surprised when they discovered that a particular activity could be physically active. For example, A2 identified the impact of little activities throughout the day: the graph and journal “told me when the intensity was greater than other times, so I was able to gauge my activities like if I just walk upstairs to get a cup of coffee.” Other participants voiced the same sentiment.

“I realized that walking up the hill on my way home burns a lot of calories, and that going shopping makes me walk a lot.” (A1)

“It was nice to see that I walked more than I thought I did. There was one day when I was babysitting. I walked so much with the baby. I walked all over campus.” (A3)

“Housework and walking to the bus stop can contribute, really. I mean, I take that for granted in terms of energy expenditure. I mean I don’t even count it when I write down what I do. But it really does make a difference.” (A4)

Participants also found opportunities for physical activity. A2 said that the information from the journal and the device “caused [her] to incorporate mini-bursts of activity into my day.” A4 said “The feedback really makes me realize that walking makes a difference, even if it’s just errands.”

While participants appreciated the detailed time-stamped data from the SenseWear armband, they missed the real-time feedback that the pedometer provided. They especially missed seeing the numbers increase as each day progressed.

To summarize, this study suggests that when given access to contextual information during reflection, people could and would associate them with their physical activity, helping them become more aware of factors that affect their physical activity. This study encouraged us to build prototypes that help people find associations between their behavior and contextual information. We describe the development and deployment of the prototypes in the following sections.

6. IMPACT 1.0 (STUDY B)

We developed the first prototype of IMPACT (*Integrated Monitoring of Physical Activity and Context*). We wanted to build a prototype that helped people easily see associations between their physical activity and contextual information, so we focused on the visualizations feature of the prototype, instead of how people tracked information about themselves. Our participants in the last study had such good compliance in collecting data that we maintained the same procedure for collecting physical activity and contextual information. We had the choice to use a pedometer or a BodyMedia SenseWear armband. We chose the pedometer because they’re easier to use (the armband can be

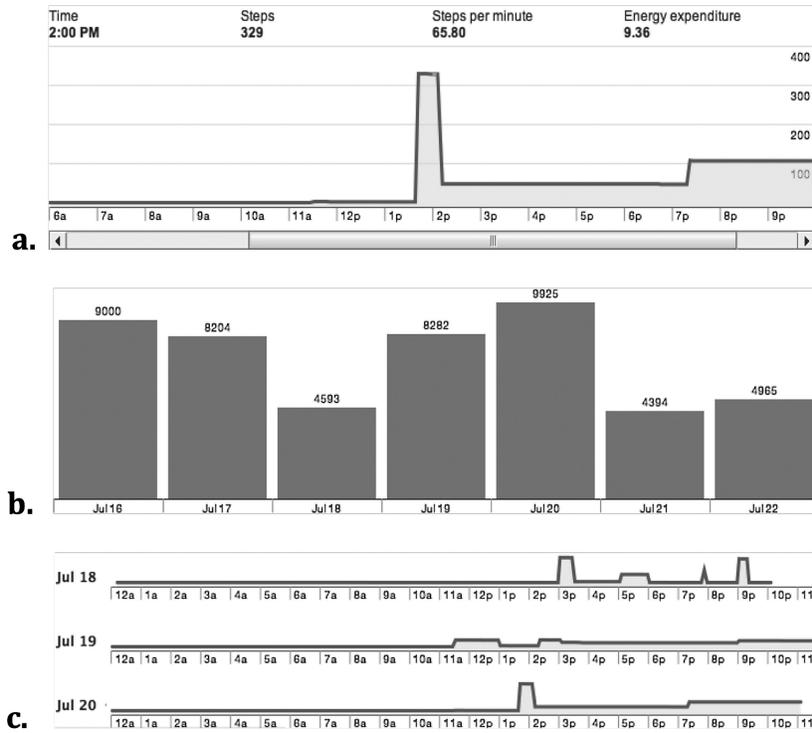


Fig. 2. Visualizations in the steps-only version of the IMPACT Web site. (a) Day view of step counts; (b) aggregated daily step counts during a week; and (c) detailed daily step counts during a week.

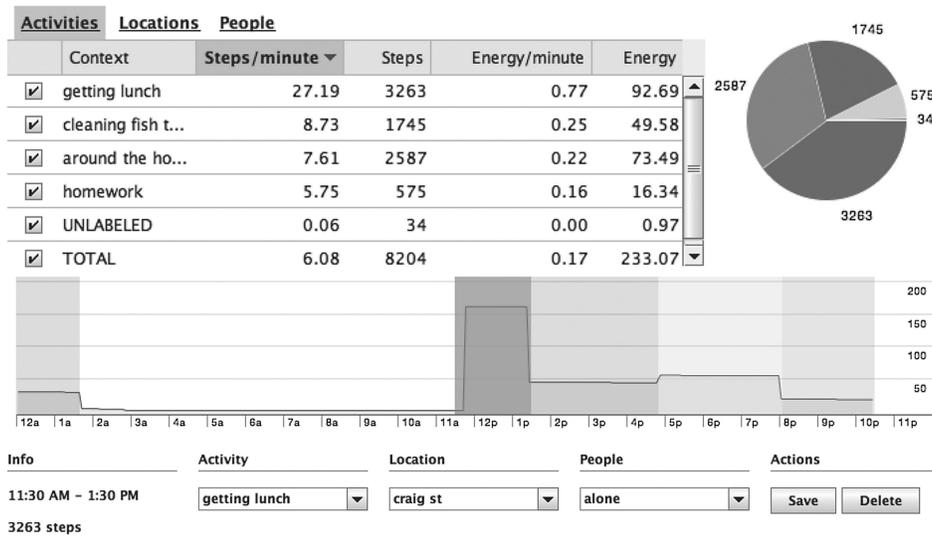


Fig. 3. Additional visualizations in the IMPACT version of the IMPACT Web site showing step counts with contextual information.

Table II. Number of Participants who Mentioned Context (including and excluding time) After Using Each of the Systems

	Control	Steps-Only	IMPACT
Mentioned Context	11 participants	13	18
Mentioned Context Excluding Time	6	7	13

6.1. Study

We expected that the prototype would help users better associate contextual information with their physical activity. With this awareness, we hypothesized that users would increase their awareness of opportunities to be physically active as we observed in the diary study.

We recruited 43 sedentary individuals (B1–B43, 14 males and 29 females) with various backgrounds from around the city proper. Regardless of step counts, participants received \$ 100 at the end of the study.

We conducted a 7-week study of the prototype: one week for the control version and 3 weeks for each of the steps-only and IMPACT versions. The last two phases were counter-balanced.

We interviewed the participants four times during the study: at the beginning and after each of the phases. We also gave them surveys in which they rated their awareness of physical activity, awareness of opportunities for physical activity, system usefulness, and ease of use on a 5-point Likert scale.

6.2. Results

Thirteen participants were dropped from the study because of sickness (1), lost pedometers (2), not responding to surveys (3), and unlike Study A, poor compliance in recording (7). We analyzed our data on the remaining 30 participants.

Results from our survey supported our hypothesis about the value of contextual information: participants reported greater awareness of opportunities for physical activity after the *IMPACT* phase (mean: 3.93, s.d.: 0.74) compared to after the steps-only phase (mean: 3.57, s.d.: 0.86) ($F[1,58] = 5.32, p < .05$). We asked participants to describe how IMPACT increased their awareness and they explained that the contextual information helped them see the factors that they did not realize had an effect on their physical activity. Here are some examples.

“The field [in the journal] I used the most was noting who I was with during my most inactive periods. I was surprised by the results—I hadn’t realized that I was so sedentary most of the time I spent with my friends.” (B1)

“It turns out I get the most walking done to and from work . . . and walking around my neighborhood for an hour or two made such a difference.” (B25)

“It helped me realize which activities were more important. For example, I didn’t understand the importance of walking home versus taking the bus.” (B8)

We also coded the responses whether they mentioned any contextual information and what type. Table II shows further proof that people actually used the contextual information that they collected. Eighteen participants mentioned context after using *IMPACT* compared to 13 (steps-only) and 11 (control). If we remove mentions of time as context, the number of participants that mentioned context after using IMPACT (13) is twice more than after using steps-only (7) or after using control (6). Participants’ awareness of their physical activity remained the same for each of the phases, which makes sense since all participants used pedometers throughout the study.

Participants also rated the IMPACT version as most useful. B11 actively used the contextual information provided by IMPACT; she said, “I used the contextual information to identify those activities that generated the most steps and if possible, I would increase those activities during the day.” B24 appreciated seeing what she was doing exactly; she said, “Being able to see what exactly I was doing at what times of the day showed me how I could work in extra walking during my breaks, and exactly how long it took me to get to work.”

While the IMPACT version was useful, it was rated the least easy to use. Participants gave several reasons why the IMPACT version was difficult to use. B4 said, “IMPACT gave a lot of cool information, but having to input all of the various factors was a hassle and made me less likely to do it on time.” B11 said, “IMPACT was too time-consuming. Sometimes it made me feel like it is actually having a negative effect! I wouldn’t want to do something different because then I had to record it. It could be really exhausting at times.”

The poor compliance during the study (we lost 7 participants because of noncompliance) suggests that all the different versions of the system had to be easier to use. In retrospect, our assumption that participants would be willing to manually record step counts and contextual information for a long time as we saw in the previous study was misguided. This study was more than twice as long as the previous study (7 weeks versus 3 weeks). However, the problem is addressable; 90% of the participants reported they would continue using the system if collection of context information were more automated.

There were no statistical differences in step counts between phases; the IMPACT version performed as well as the control and steps-only versions, which are similar to regular pedometers. This may be caused by the realities of running field studies: (1) there are many factors that can affect physical activity throughout a month that we cannot control; (2) we only had few participants per condition; and (3) the variability of the step counts by each user and between users is too high to get a significant result. All we can conclude about the effect of contextual information on level of physical activity from this study is that the extra load of recording contextual information did not deter physical activity.

Another limitation of the study concerns the length of the 1-week-long control phase compared to the 3-week-long steps-only and IMPACT phases. The brevity of this phase may have resulted in unrealistic baseline step counts because of the novelty effect [Clark and Sugrue 1988]. The control phase should have been the same length as the other phases. Despite this concern, if there were a novelty effect, we expected the control step counts to be significantly more than the other phases, but this did not occur.

This study provides empirical evidence that associating contextual information with physical activity can increase participants’ awareness of opportunities for physical activity. Additionally, the extra load of recording contextual information did not deter physical activity. While participants found the IMPACT system useful, they commented that it was hard to use, due to the need for manual collection of context and transcription to the Web site. We addressed this problem with a semiautomated prototype which we describe in the next section.

7. IMPACT 2.0 (STUDY C)

We created a second version of the IMPACT system that addresses the problems identified in the previous study. Instead of a pedometer and a journal for manual recording, this version uses a mobile phone and GPS to monitor step counts and the user’s location. The mobile phone also has an easy-to-use interface to input what the user is doing and whom he/she is with.



Fig. 4. Monitoring device for the second version of IMPACT. Nokia 5500 Sport (left) and detailed view of the display (right).

7.1. System

The mobile phone we used in our prototype is the Nokia 5500 Sport, which has a built-in 3-dimensional accelerometer. The phone contains software to count steps, but the algorithm is not as accurate as the Omron HJ-112 used in our previous trials. Instead, we wrote our own pedometer application in Python to run on Nokia's Symbian OS (Figure 4). We modified a step-counting algorithm from the Robert Bosch Corporation to match the accuracy of the Omron HJ-112 pedometer. We tested this with 5 users over several days of routine use and tuned the algorithm until we matched the Omron pedometer within $\pm 5\%$. The pedometer application stores the user's step counts per minute and displays the user's aggregate step counts for the day and for each of the past 5 minutes.

The Nokia 5500 Sport does not have an internal GPS, so we used a separate Bluetooth GPS module (Nokia LD-3W) to collect location information. The GPS module scans the user's location every minute, which is then stored by the phone application.

The phone application collects additional contextual information using activity-triggered experience sampling [Froehlich et al. 2007]. When the user is active or inactive, the phone vibrates to prompt users to select from a list: what they were doing (events) and whom they were with (people). The list is prefilled with 5 common activities (e.g., grocery shopping, walking) and 5 usual companions (e.g., friends, family, coworkers), but users can enter new labels. We did not implement automatic labeling of events and people because such classification requires additional sensors that may not be robust enough for a long-term field study or are still not mainstream and widely available. For example, the UbiFit Garden [Consolvo et al. 2008] used a combination of a mobile phone and the Intel multisensor platform research prototype to partially automate recognition of exercise activities, such as walking, running, biking, and using a stair machine.

We also implemented a new version of the Web site (Figure 5), which showed the association between daily activities and step counts on (1) a timeline of the user's steps with time segments labeled with contextual information; and (2) a histogram of the total number of steps associated with a particular label (e.g., 400 steps at work, 1300 steps at the grocery store). Instead of manually entering step counts and contextual information on the Web site, a desktop application synchronized data between the phone and the new Web site. If the user needs to add more contextual information after uploading, they can label periods of time on the visualizations.

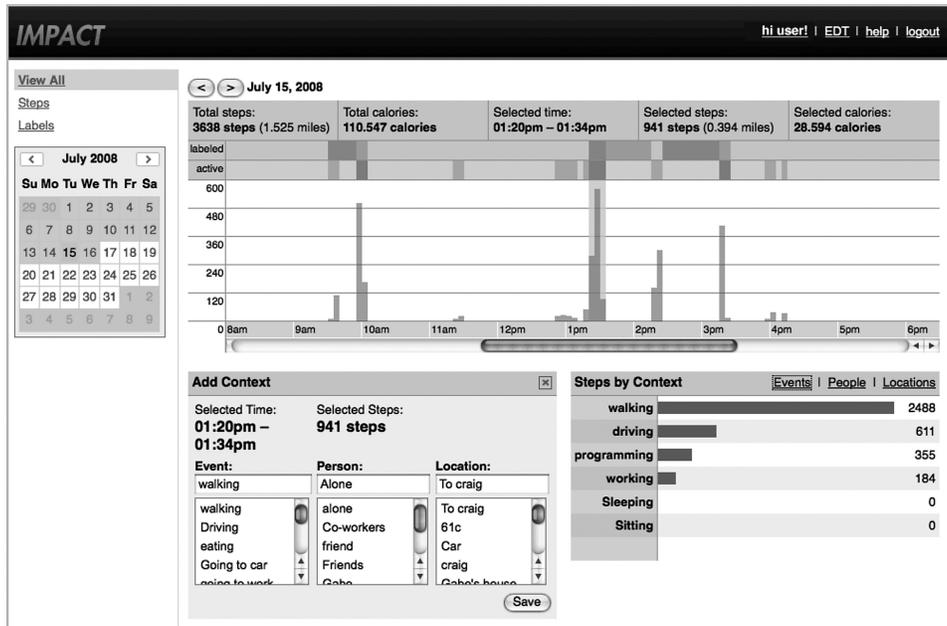


Fig. 5. Visualizations in the IMPACT Web site showing step counts with contextual information. Detailed step counts graph with contextual annotations (top) and context graph (bottom right).

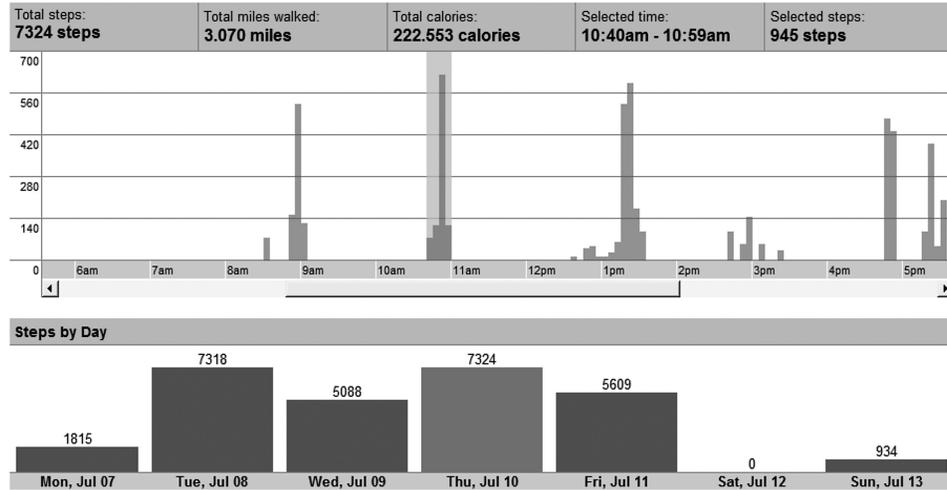


Fig. 6. The steps-only version of the system only had the visualizations above. Top: day view of step counts. Bottom: aggregated daily step counts during a week.

We also implemented two other versions of the system: steps-only and control. The steps-only system only monitored step counts and the Web site only showed daily step counts without any contextual information (Figure 6). The mobile phone still alerted users when they had been active and inactive, but they were just asked to rate how active they were on a 5-point Likert scale (not at all active to very active), to make the interruption comparable to the IMPACT version. The control system also only

monitored step counts, but we removed visualizations on the Web site. Essentially, it is similar to an off-the-shelf pedometer.

7.2. Study

Similar to the first IMPACT prototype, we expected that the second version would help users better associate contextual information with their physical activity. We hypothesized that users would increase their awareness of opportunities to be physically active.

We conducted an 8-week-long study: four weeks for a baseline phase and four weeks for an intervention phase. During the baseline phase, all participants used the control system. During the intervention phase, participants were randomly assigned to three types of interventions: control, steps-only, and IMPACT. We told participants to synchronize their data at least every other day, so we could ensure usage and promptly see any technical issues with the system.

We recruited 49 participants (C1–C49) aged 18 to 60 using the same recruitment method as the previous study. Regardless of their step counts, participants received \$50 for completing the baseline phase and \$ 75 for completing the intervention phase. Successful completion meant that data was uploaded on a consistent basis.

We met the participants three times: at the beginning and after each phase. During the meetings, we introduced participants to the system they would use, interviewed them, and gave them surveys similar to the previous study.

Participants did not use the IMPACT phone as their primary phone. This prevented frustration with having to use a new phone and interoperability problems between phone communication and monitoring functions. However, this risked users not carrying the device. We experienced problems with some participants, but most were compliant.

7.3. Results

We performed the analysis of the data we collected on 35 out of the 49 participants that started the study. Thirteen participants dropped during the baseline phase because of family issues and scheduling problems (4); not wearing the devices for several days (4); disappeared and never returned the phones (3); losing the phone (1); and not responding to our emails (1). One participant dropped out during the intervention phase because she got into an accident. Despite the attrition, the remaining participants were still evenly distributed between the interventions: 12 participants in control, 12 in steps-only, and 11 in IMPACT.

7.3.1. Average Step Counts. We prepared the physical activity data by removing days where participants did not wear the device for more than nine hours. Days with more than six hours with zero steps in the middle of the day (suggesting the phone was not worn) were also removed.

Adding the total steps for each day and dividing it by the number of days produced the average steps for each phase. We performed a repeated-measures analysis of the differences over the two phases between the groups. There were no significant changes over the course of the study between the different groups (no interaction, $F[2,32] = 0.15$, $p = 0.86$). We also ran the analysis with the phases broken into weekly segments, but found no differences. In general, participants maintained the same amount of physical activity between the two phases. Again, recording contextual information did not deter physical activity and the IMPACT system performed as well as the steps-only and control versions, which are like pedometers.

7.3.2. Awareness of Opportunities. We checked to see if the IMPACT system helped participants increase their awareness of opportunities to be active. There was a marginally

Table III. Number of Participants who Mentioned Context (including and excluding time) After Using Each of the Systems

	Control	Steps-Only	IMPACT
Mentioned Context	6 participants	8	8
Mentioned Context Excluding Time	5	3	6

significant main effect of phase on the awareness of opportunities ($F[2,32] = 3.98$, $p = .0547$). Awareness of opportunities increased for all groups, which is not what we expected. Similar to the analysis in the second study, we coded participants' responses to how the systems increased their awareness of how/when they can be active. Unlike the previous study, contextual information did not make users of IMPACT more aware of how/when they can be active compared to the other versions (Table III). Eight participants who used IMPACT mentioned context compared to eight (steps-only) and six (control). Even after removing time as context, the number of participants who mentioned context after using IMPACT (6) is similar to after using steps-only (3) or after using control (5).

One explanation why awareness increased with the first version of IMPACT but not the second is that users of the first version were more engaged with their data; they had to observe their behavior, physically write down their contextual information in a booklet, and transcribe the data onto the Web site. On the other hand, while the second version eased the burden of data collection, users were less engaged with their data; the prototype tracked the user's physical activity and location and the data was automatically synchronized with the Web site.

We also have evidence from our interviews that simply carrying around the extra device, being confronted with real-time information about steps taken, and knowing that they were being monitored were enough to give all users some idea of opportunities for physical activity.

"I have tried to make a point of making more trips across the office rather than waiting to make one trip." (C34, Control)

"I began to see the contribution of a short-distance walk to my overall emotional and physical health. I used to be a very sedentary person. I realize if I do not walk on purpose, my physical exercise will be zero. So I take a short walk whenever possible, then I feel good about it." (C12, Steps-Only)

"The system helped me realize how exercise can be built into your daily schedule. I tried to maximize those opportunities by walking whenever possible instead of taking the bus." (C24, IMPACT)

Contrasting this result from the results of the previous study suggests an important implication for applications that integrate contextual information to increase awareness. It suggests that user engagement is very important and that taking away too much of the responsibility for monitoring from the user may have a detrimental effect on immediate awareness. However, this is a difficult issue to balance. One solution might be to supplement the engagement lost during the collection of the data by encouraging users to reflect on their data more often (e.g., look at the visualizations at the end of each day, alert users to look at important data points).

As we saw in the previous study, some form of automation is necessary because it relieves the burden of monitoring on the user. What good can the application provide if the user will not use it? We conducted a follow-up interview with participants to explore this issue further.

7.4. Follow-Up Interviews

We conducted follow-up interviews with participants six months after the study to see if people could revisit, reflect, and use their collected data in the study to learn about

opportunities for physical activity. Fourteen participants responded to our request: 5 from control, 6 from steps-only, and 3 from IMPACT. During the interviews, we asked them about their physical activity and their experience with the different systems. We also had them reflect on their physical activity during the study by exploring their data on the Web site.

Participants repeated what they said about finding opportunities to be physically active during the study. However, there were some important observations while reflecting on their data that suggest automatically collected contextual information may still be useful. All participants were curious about the peaks that they saw in their graphs; they wanted to know what they were doing during those times of peak activity. Participants in the IMPACT group had no problems finding out what they did because the peaks were labeled. They were often surprised to find out that they had performed such an activity during the study. On the other hand, participants in the control and steps-only groups could only guess at what they did. For participants with regular routines, they were able to deduce what they did by looking at the time of the peak. Interestingly, some participants pulled out their electronic calendars to see what they were doing on a particular date to deduce what the peak meant. One participant said that she would look back at her email and instant messenger history to find out how she was feeling during the days of peak activity guessing that her mood had an effect on her physical activity.

These observations imply a few design considerations for systems. First, automatic labeling of contextual information is useful for reflection, especially at a later time when the user has likely forgotten her history. In fact, most participants told us that they wished the study ran longer than the two months; they were interested in finding out how their physical activity compares six months ago to their current activity. This suggests that physical activity awareness applications that provide information in the long term can benefit from contextual information. Second, existing records, such as electronic calendars and email, can be leveraged to provide contextual information. A paper by Schwarz and colleagues [2009] suggests that financial records can be used to infer activity and location. Since many people have financial statements, this may be a ready source of contextual information. Lastly, the use of contextual information that is important to physical activity should not be limited to activities, places, and people. Other information, such as mood and weather, may also be important. This makes sense since there are many kinds of barriers to being physically active [Centers for Disease Control and Prevention 2008; Sallis and Hovell 1990], including lack of motivation and weather conditions.

8. GENERAL DISCUSSION

We present three major findings from our studies. First, when given access to contextual information and physical activity information, users can and do make associations between the information helping them become aware of factors that affect their physical activity. Second, reflecting on physical activity and contextual information can increase people's awareness of opportunities for physical activity. Lastly, automated tracking of physical activity and contextual information increases the amount of data collected by the user, which benefits long-term reflection, but may be detrimental to immediate awareness. We believe these results are applicable to the use of contextual information to reveal factors that affect other types of behaviors, for example, diabetes management and energy conservation. These contributions suggest that personal informatics systems should further explore incorporating contextual information.

There are a few limitations to our field studies. First, the field studies focused on three types of contextual information: activities, location, and people. However, participants indicated that other types of contextual information might be more relevant to

their physical activity, such as mood and weather information. This suggests an opportunity to explore ways to facilitate integration of other types of contextual information with physical activity information. Additionally, it would be interesting to explore ways to help users determine the kinds of contextual information they should collect that would yield the most insights. Second, the field studies were limited in time and number of participants to properly detect changes in physical activity. Many studies in human-computer interaction can be conducted in a controlled environment; thus, 30 participants may be sufficient to yield significant results. However, we had to conduct our studies in the field because we are exploring physical activity. Field studies are inherently less controlled, which means that there is higher variability between users and situations from day to day. In order to properly detect changes in physical activity, it might be necessary to conduct field studies with more participants (in the hundreds or thousands) over a longer period of time (several months to a few years). Lastly, we focused our exploration only on three of the five stages of personal informatics systems [Li et al. 2010]: collection, integration, and reflection. We did not explore ways to support the action stage, which is the stage when people act on their newfound knowledge. We did this because the model of personal informatics indicated that problems from the earlier stages affect the later stages; thus the action stage is highly dependent on how the earlier stages are supported. Our field studies highlighted some issues in how the earlier stages should be supported. With these insights, future research can focus more on the action stage by exploring persuasive technologies, behavioral economics, and game mechanics.

The studies showed that contextual information offers value in reflecting on physical activity levels. Study A showed that people could and would associate contextual information with their physical activity to become aware of factors that affect their physical activity. Study B provided empirical evidence that reflecting on contextual information can increase people's awareness of opportunities to be physically active.

Physical activity awareness systems were among the first personal informatics tools. However, most have not grown beyond physical activity levels. We show that contextual information adds richness to the data. While we studied a personal informatics system that incorporated contextual information for physical activity, there may be opportunities for adding contextual information in personal informatics systems for other domains as well. The work of Mamykina and colleagues [2006] and Frost and Smith [2003] suggest that extra information about factors that affect blood sugar levels would be appropriate for people with diabetes. In addition, contextual information in personal informatics systems to assist with living sustainably and smoking cessation may also be useful.

Personal informatics systems need to better integrate collection of and reflection on the data. In all the prototypes, the users were involved in varying degrees during the collection of data (they had to wear a device and record other information) and during the reflection on the data (they had to actively explore the information to find patterns and trends). Study A suggested that people need an easy way of associating their physical activity with contextual information. We resolved this in Study B with a prototype that has a Web site for visualizing this information. There are other approaches that warrant further exploration. For example, making a system that finds conclusions from the users' data can make the exploration more automatic. However, building such a system first requires identifying what information people want to know more about. Additionally, we can reverse the relationship between the system and user. Instead of the system passively displaying information and the user actively seeking information as in our prototypes, a system may proactively provide suggestions based on observed patterns of user activity, like a virtual coach or physical trainer.

Easing the burden of collecting data is complicated. We found in Study B that monitoring needs to be easier. We addressed the problem in Study C with a prototype that uses a mobile phone for tracking step counts and a GPS tracker for monitoring location. We found that the IMPACT version, which automatically collected contextual information, was not better at improving users' awareness of opportunities for physical activity compared to the steps-only systems, which only collected step counts. In fact, they both increased users' awareness of opportunities for physical activity. We attributed this problem to the semi-automated collection of the contextual information. Whereas Study B participants were active in recording their contextual information, Study C participants were less active. Interestingly, this poses a tricky trade-off between ease-of-use and the value of contextual information. This trade-off requires further exploration. One direction to explore is balancing the engagement lost during the collection of the data with more engagement during the reflection on the data. For example, a system might encourage users to look at their data more often by telling users to look at visualizations at the end of each day, or by alerting users to look at important data points.

While automation may have had a detrimental effect on immediate awareness, automated tracking of physical activity and contextual information benefits long-term reflection. In Study C, participants indicated that they wanted to record for longer periods of time; they wanted to be able to compare their physical activity between months, seasons, and even consecutive years; and most importantly, they wanted integrated contextual information that would help them make sense of their data months after it was collected. If the cost of collecting information was high (e.g., manually collecting several pieces of information like in Study A and B), users may not provide labels for such a long period of time and they would not be able to effectively reflect on their past history. Future systems can explore other ways of keeping users active with their data while automatically collecting contextual information using better monitoring devices or through indirect information, such as calendaring systems. Our long-term field studies suggest that there is an interaction between time and the value of contextual information. How people's experiences with physical activity awareness systems change with time needs to be explored more. We do not know whether this is important for all personal informatics systems, but for systems that provide information about one's physical activity, it seems that it is important.

9. CONCLUSION

We have presented our exploration of how contextual information can reveal factors that affect behavior. Focusing on the domain of physical activity awareness, we developed prototypes and conducted a series of studies that supported reflection on physical activity with contextual information. We found that people can and do make associations between physical activity and contextual information when given access to both types of information. We provided empirical evidence that contextual information can be used to increase awareness of opportunities for physical activity. The field deployments suggest that easing the burden of data collection is important, since contextual information is critical when reflecting on one's physical activity in the long term. However, systems must help people maintain awareness of their physical activity and contextual information in the short term. This work suggests new opportunities for research in personal informatics systems and for exploring the role of contextual information in self-reflection and self-knowledge.

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