"My blood sugar is higher on the weekends": Finding a Role for Context and Context-Awareness in the Design of Health Self-Management Technology

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ABSTRACT

Tools for self-care of chronic conditions often do not fit the contexts in which self-care happens because the influence of context on self-care practices is unclear. We conducted a diary study with 15 adolescents with Type 1 Diabetes and their caregivers to understand how context affects self-care. We observed different contextual settings, which we call *contextual frames*, in which diabetes self-management varied depending on certain factors - physical activity, food, emotional state, insulin, people, and attitudes. The relative prevalence of these factors across contextual frames impacts self-care necessitating different types of support. We show that contextual frames, as phenomenological abstractions of context, can help designers of context-aware systems systematically explore and model the relation of context with behavior and with technology supporting behavior. Lastly, considering contextual frames as sensitizing concepts, we provide design directions for using context in technology design.

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CCS CONCEPTS

• **Human-centered computing → Empirical studies in ubiquitous and mobile computing**; *Empirical studies in HCI*.

KEYWORDS

Personal health informatics, diabetes management, context-awareness, mobile health, chronic disease, just-in-time interventions

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1 INTRODUCTION

The prevalence of chronic health conditions has been on the rise [45]. By 2020, 157 million people are projected to have at least one chronic health condition [21]. Among these conditions, diabetes (including type 1 and type 2) is the 7th leading cause of death and can result in health complications, such as vision loss, kidney malfunction, and cardiac issues [15]. Despite the risks associated with diabetes, adherence to self-care behaviors among patients is an ongoing problem across all ages [32, 46].

American Diabetes Association has recommended the use of mobile applications as an approach to encourage healthy lifestyle for the prevention of diabetes [4]. The efficacy of simple mobile health interventions in improving health outcomes [47] has triggered the development of more sophisticated approaches to support management, such as just-in-time adaptive interventions (JITAIs) [25] and anticipatory computing [31], to guide health-related behavior. These approaches use data sensed from smartphones for context-aware delivery of support, that is providing support at the right time, at the right place, and in the right way.

While interventions that employ context-awareness have resulted in encouraging outcomes [40], designing such systems remains a challenge. For example, understanding the scope and relevance of contextual factors in relation to behaviors being supported or diminished is not straightforward. That is, among the multiple factors that could affect health management and that could be sensed, which ones are relevant and how should they be used? [6].

To support design decisions related to the inclusion of context in systems, researchers have suggested the need for high-level abstractions of context to improve the intelligibility of context-aware systems for designers and developers [12]. While existing abstractions expose context in relation to an application and its features, they don't help understand the role of context in relation to user behaviors. In the domain of health self-management, context-driven investigations of specific behaviors can illuminate the role of context and context-awareness in influencing the behavior and hence, in designing technology to support that behavior [22].

In this direction, we conducted a 3-week diary study with 15 adolescents who had Type 1 Diabetes and their caregivers. Using multiple streams of data collected through a context-enhanced diary tool, end of day diary responses, and data from interviews with patients and their caregivers, we investigated the lived experiences of diabetes management. We observed that diabetes self-management varied across different contextual settings (School, Home, Work, Travel, Summer, Weekends, and Weekdays), and this variance in turn resulted from the changing relevance and influence of factors (physical activity, food, emotional state, insulin, people, and attitudes) within each setting. To make sense of these variations, we introduce the notion of *contextual frames* to denote recurring high-level contexts in which particular factors can influence behavior and can take on different degrees of relevance. We show that contextual frames help portray the relationship of a collection of contextual factors to health self-management practices, making them blueprints for systematically exploring and representing such relationships. We show that contextual frames as sensitizing concepts contribute design knowledge to improve the design process of context-aware systems by prompting designers to explore new design directions. Informed by the notion of contextual frames with regards to health self-management, we specify implications for the design of systems using context and context-awareness to support self-care.

2 RELATED WORK

In this section, we summarize research in two relevant areas - diabetes self-management (the use of technology and the role of context), and context and context-awareness in health.

Technology for Diabetes Self-Management

Diabetes is a metabolic disease in which the pancreas is unable to produce or use insulin effectively [27], resulting in the need for multiple self-care activities to control blood glucose (BG) variations - healthy eating, being active, monitoring, taking medication, problem-solving, reducing risks, and healthy coping [28]. This has resulted in systems designed to support these activities, offering features such as carb counting [18], diary keeping [44], and reflection [7, 23, 39]. In particular, the use of mobile applications is associated with improved glycemic control in different populations [7]. However, research in Human-Computer Interaction and health communities has identified that existing systems do not match the evolving needs and preferences of patients [8, 20, 42] and are burdensome to use [43]. These shortcomings indicate the lack of contextualized understanding of diabetes self-management practices, which results in technology that provides recommendations or support with insufficient understanding of the context in which support is needed. This calls for understanding the role of context in impacting self-management behavior.

Influence of Context on Diabetes Management

Many studies have reported health self-management practices of patients with diabetes and their caregivers. The majority of these studies highlight how patients need to negotiate everyday activities in different contextual conditions, such as planning, finding, informing, calculating, and remembering [19]. In order to do so, they have engage in practices, such as, capturing relevant and motivational information [41, 43], associating consequences to actions [8, 24], discovering health information [8], personalizing guidelines [42], and handling the emotional burden of diabetes [8, 43]. For adolescents, caregiver involvement requires remote monitoring in addition to self-monitoring, especially when parent and child are not collocated [43]. While these studies highlight how practices are influenced by context, they do not focus on providing design considerations for context-aware systems.

A limited number of studies have focused on developing applications that leverage context to support diabetes management. The use of context is primarily limited to promoting reflection by augmenting clinical data with context data [7, 17, 33]. Beyond reflection, context can be used to deliver other services to the users, such as providing reminders and health tips, suggesting treatment, and initiating provider contact [26]. While these have been explored for a few conditions that include mood disorders [5] and spinal cord injuries [1], the complexity of designing such applications is a challenge that researchers still face. This points to the need to better understand how can we model context-behavior relationships that can be derived from lived experiences and translated into system features.

Context and Context-Awareness in Health

Many categorizations and definitions of *"context"* and *"context-awareness"* exist in literature but no single definition or categorization scheme is comprehensive enough to accommodate what context means in different domains of application [3]. A widely used definition of context is *"any information that can be used to characterize the situation of entities (i.e. whether a person, place or object) that are considered relevant to the interaction between a user and an application, including the user and the application themselves"* [11]. A system is said to be context-aware if *"it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task"* [10].

The proliferation of sensor rich smartphones has enabled creation of context-aware mobile health technology to support healthy lifestyles and the management of chronic health conditions. Systems explored in the literature have provided personalized reminders and health behavior recommendations using information sensed from smartphones [5, 34], just-in-time adaptive interventions [25], and predicting health-related behaviors [31]. Such interventions are well-suited to meet the evolving and situated user needs by recognizing real-life situations and responding to them. Although the use of context in healthcare has received substantial research attention, understanding the role of context for health-related behavior and needs to create context-aware applications remains a challenge [6].

In HCI research, context-enhanced displays of biomedical data have been used to aid reflection, which helps patients and researchers understand relevant lived-experiences [29, 39]. In one study, such displays were used by experts to elicit requirements for just-in-time interventions [38]. In a similar direction, through a context-driven investigation of diabetes management, this study aims to explore the role of context in affecting diabetes self-management behavior and in designing systems to support the same.

3 METHODS

The objective of this study was to understand the role of context in impacting self-management of diabetes. That is, understanding diabetes management in different living conditions and the associated challenges. We chose to study Type 1 diabetics as this condition is affected by multiple, well-known factors (e.g., food, insulin, exercise, and stress) and requires responding to changes in these factors by adjusting management. Since Type 1 diabetes usually begins in childhood or adolescence and only rarely in adulthood [16], we chose to study adolescents.

Patient and Caregiver Recruitment

Patients and their caregivers were recruited from a pediatric endocrinology clinic at a large teaching hospital. We recruited patients who were 13-17 years of age, English speaking, and were willing to perform the study tasks. 15 patient-caregiver dyads completed the study, each receiving $75 in compensation upon completion. Table 1 provides details for all the adolescent participants including the devices they used for management (continuous glucose monitors (CGM), conventional glucometer (Meter) and insulin pump (Pump)). We chose to recruit the caregivers as during adolescence, patients are considerably dependent on their parents for guidance on disease management [37]. For all the participants, their mothers were the primary caregivers who participated in the study.

Data Collection

There were three main phases of data collection - initial interview, 3-week diary study, and the exit interview. In an hour-long interview at the beginning of the study, we gathered demographic information about the patients. We then demonstrated the use of DReflect (Figure 1), the mobile application used by participants for data collection, and explained the tasks expected of them for the three-week diary study. As a part of configuring DReflect, participants were asked to label and save specific locations that they were going to frequently visit during the three-week study period (e.g. home, school, work, soccer practice, etc.) and wake up and bed times. Lastly, patients and their caregivers were interviewed to understand the patient's daily routine and engagement with diabetes self-care activities.

For the diary study, we developed a context-enhanced diary tool, DReflect, which was used by our adolescent participants to collect data for three weeks. Patients were asked to log their meals (images and carbohydrates), blood glucose (BG) number, insulin (basal and bolus [13]), mood, and contextual factors affecting their management and routine through hashtags and notes for 21 days. At the end of each day, they were reminded by the mobile app to fill in a diary that showed a context-enhanced summary of the data reported from that day (Figure 1.c), followed by questions to understand critical incidents for that day (diabetes and non-diabetes related), challenges of managing diabetes for

Table 1: Summary of adolescent participants

ID	Age (years)	Gender	Work	Main Physical Activity	Devices Used
P01	14	F	No	Gymnastics	CGM, Pump
P02	17	M	Yes	Tennis	CGM, Pump
P03	15	F	No	None	CGM, Pump
P04	17	F	Yes	None	Meter, Pump
P05	16	F	No	Marching Band	Meter, Pump
P06	16	M	Yes	Cross Country, Ski, Track	CGM, Pump
P07	16	F	Yes	Gymnastic	Meter, Shots
P08	14	M	No	Swimming	CGM, Shots
P09	17	M	Yes	Running	CGM, Pump
P10	13	M	No	Soccer, Swimming	CGM, Pump
P11	15	F	No	Golf, Horse Riding	CGM, Pump
P12	13	M	No	Running, Soccer	Meter, Pump
P13	16	M	Yes	Gym, Football	Meter, Pump
P14	13	F	No	None	Meter, Pump
P15	13	F	No	Dance, Yoga	Meter, Shots

the day, and other things that they might wish to share or forgot to report during the day (Figure 1.d). Participants' responses included BG numbers, carbohydrates, food images, glucometer images, bolus insulin, and notes.

Figure 1: The DReflect System a) meal log screen, b) mood report screen, c) end of day data summary, and d) end of day questions

We also asked caregivers to fill diary entries for 21 days. They were asked to report about their day, the routine of their family, any unusual events in their day and their child's day, and the challenges of managing diabetes for that day. Caregivers were emailed a link to an online questionnaire every day at a time they chose in the initial interview. The majority of the caregivers reported diary entries for all 21 days. After the study, we conducted an hour-long exit interview with the patient and the caregiver separately. During the interview, we first asked participants to walk through summary visualizations of their data while thinking aloud. Next, we asked them questions focused on days that were unusual or that involved a critical incident as identified from the diary data. These questions were supplemented with day-wise displays of their data to enable recall and reflective conversation. An exit interview document consisting of visualizations and questions was sent to the participants before the interview. Reflecting on outcome measures along with contextual data has shown to create more awareness of one's own behavior [22]. Participants' responses helped us understand how they used data to get insights about diabetes management and their actual experiences of managing diabetes. In this paper, we report on the latter to provide an understanding of how context affects diabetes self-care.

Data Analysis

We analyzed the data in two phases. After the diary study, diary entries and initial interviews were analyzed to understand breakdowns in management and difficult and/or atypical circumstances for each participant. These insights were used to prepare exit interview documents consisting of displays of the patient's data and questions about events that took place during the study. At the end of the study, we re-analyzed initial interviews and the exit interviews using in vivo and descriptive coding[35] to understand different settings for self-management and factors influencing management. The research team met multiple times throughout the data analysis process to iteratively refine the list of factors and settings and to elaborate these themes further, while dropping the less prominent themes.

4 FINDINGS

In understanding the influence of context on diabetes self-management, we observed that self-management happened in recurring contextual settings (such as Home, School, etc.) wherein multiple factors (such as physical activity, food, etc.) converged to influence self-management. We also observed that these factors had different impact in different contextual settings, as described by our participants. While these observations might seem obvious as prior work also points to the influence of context in the management of diabetes [8, 19, 24, 42, 43], there is limited exploration and articulation of how lived experiences of patients can be systematically captured to model context-behavior relationships and inform the design of context-aware systems.

To better explain the influence of context on health self-management behaviors, we introduce the notion of *contextual frames* informed by the lived experiences of our participants. We define contextual frames as recurring physical, temporal, and/or social contexts that significantly shape the behavior of the individuals who inhabit them by inhibiting certain behavioral choices and facilitating others. Importantly, within different contextual frames, particular factors (i.e., observable states of people, environments, and systems) that might be drawn upon to characterize a situation, predict an outcome, or influence behavior can operate differently - taking on different degrees of relevance and even different relationships to the situations, outcomes, and behaviors of interest.

Different contextual frames that emerged from the lived experiences of our participants include Home, School, Work, Travel, Summer, Weekend and Weekday. Factors that we found to be relevant in different degrees across frames include location, time, physical activity, food, emotional state, insulin, people, and attitudes. Frames are collections of factors and can be tightly bound to factors that are more likely to be stable and/or predictable for a user. In our data, the majority of the descriptions that participants used revolved around physical, temporal or social settings that they regularly inhabited. This led to us to create frames bound to these factors as reflected in their names. Other than physical, temporal, and social contexts, frames could be bound to other stable factors, such as physical activity, if the user performs fixed activities (e.g., strength training on Weekdays and running on Weekends). If frames are bound to frequently changing factors, such as emotional state, the result would be multiple frames that might not be significantly different from each other.

In what follows, we present vignettes showing how contextual frames emerge from our participants' description of their experiences. We further describe the role of specific factors and how these roles changed in different contextual frames.

Contextual Frames and Variations Across Frames

In this section, we present three scenarios derived from our participants' description of diabetes-self-management that depict the different settings in which diabetes was managed, the factors affecting management in different settings, and the variations in self-management across these settings. These vignettes bring out the similarities and differences between the different frames, within and between patients, hinting at the different types of self-management support that might be appropriate for each patient and for each frame. These differences can be attributed to the different ways in which multiple factors (described in the next subsection) converge to impact diabetes management within different frames. Participants experiences further show how transitions from one frame to another can introduce challenges.

Case 1: Transitions between Home, School, and Work.
Nick, a 16-year old boy, attends high school and works at an ice cream shop. On a typical day, he wakes up at 6 am, gets ready, drives to school, and eats a protein bar at school. During lunch, he has the same food every day from the school cafeteria and has decided on a steady dose of insulin that works for him. After school and before work, he spends time at home doing various activities. He leaves for work at 6pm without having dinner. While he works, he carries a bottle of juice to avoid low blood sugar levels that might result from continuous walking and standing at work. He drives home from work at 10pm and eats a big dinner alone without his parents. Late dinners result in high BG numbers overnight and the next morning, making it a struggle for Nick to manage those. He is off work for two days a week where he does not eat a late dinner and has better BG numbers. He thinks his insulin needs to be adjusted on work days to account for the large dinner close to bedtime. He also thinks that he is able to better manage diabetes on weekdays because of a fixed schedule than at home during weekends because of an unstructured schedule.

In the above vignette, the settings of Home, School and Work, which we call contextual frames, are characterized by certain factors, such as food, activity, insulin, location, time, and attitude towards diabetes management. Figure 2 is a visual representation of the contextual frames and the constituent factors affecting diabetes as described in the above vignette. Text highlighted in red shows factors that cause or could cause problems for diabetes self-management. For example, when Nick is at work, he tries to mitigate risk, such as low BG numbers because of higher activity levels, by carrying a bottle of fruit juice. There are differences in these factors across settings, resulting in differences in diabetes self-management. For example, Nick eats dinner closer to bedtime on work days whereas an early dinner on non-work days. This results in a need for different insulin dose settings for these two types of days, which Nick has been wondering about. Similarly, the first half of Nick's day, spent primarily in school, is more structured as compared to the second half of the day, resulting in better diabetes control in school.

Case 2: Transitions between Summer and School, and Weekdays and Weekends.
Viola, a 14-year old middle schooler, was diagnosed with Type 1 diabetes two years ago. A new school year recently started after the summer vacation. During the vacation, she was home most of the time or traveled with her parents and she noted better BG numbers. From the time that school started, while

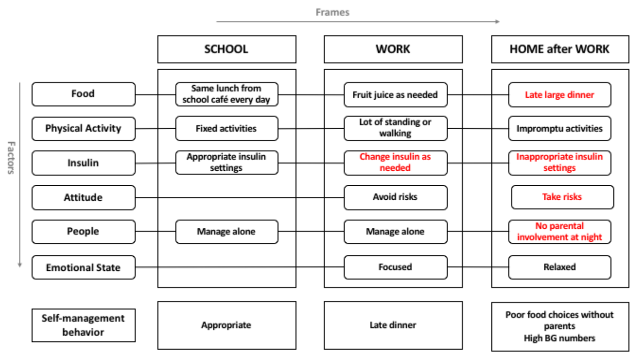


Figure 2: Nick's contextual frames and factors

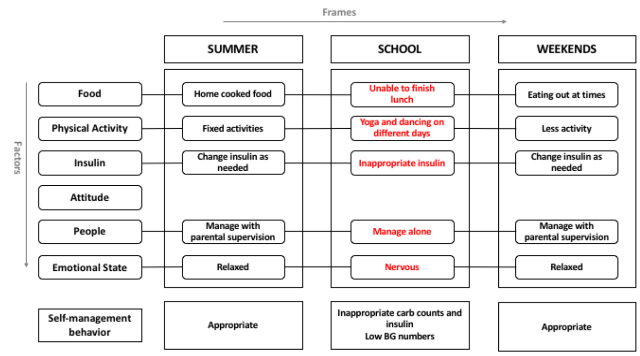


Figure 3: Viola's contextual frames and factors

she remembers performing self-care activities better because of a fixed schedule, she has been recording out of range BG numbers and has been finding it difficult to control her BG numbers during school hours. She tends to miscount carbohydrates or not finish the entire meal that she took insulin for. She is increasingly getting nervous about not being able to manage well in school. During the current school year, she has yoga and dancing classes on different days, both of which also affect her BG numbers differently. Over the weekends, she has parental assistance for diabetes management, eats out at times, does less activity, and has better BG numbers. During the summer, she noted that weekends and weekdays were similar resulting in good BG number control on both types of days but not during the school session.

Figure 3 shows the contextual frames and factors relevant for Viola. In Viola's case, the transition from summer to school has introduced challenges as managing at home with parents during the summer was different from managing at school alone. In school, the challenges was not to remember to perform self-care activities but to control BG numbers because of not being able to finish lunch and work around the effect of different activities on her BG numbers. During the summer vacation, weekends and weekdays were very similar for her with good control on BG numbers. During the school year, weekends were better than the weekdays because of parental support.

Case 3: Transitions between Summer camp, Work days, Weekends, and Weekdays.

Kevin, a 17-year old high schooler, attended a diabetes summer camp as a peer coach to help other camp attendees with diabetes. During the camp, he had very little time to manage diabetes with the peer coach responsibilities and had a lot of low BG numbers because of the hectic work. The food choices further disrupted his diabetes management because of the inability to guess carbohydrates in the camp food. As a result, he suspended his insulin pump often in the hope to avoid low BG numbers. After the camp, he started working at a pizza shop for the remaining duration of the summer. He realized his BG numbers were more stable and less extreme when he started working. He thought it was because of continuous walking or standing and because he wasn't continuously snacking at work, which he did at home. On weekends, he usually has friends over and plays video games all day. He feels awkward managing diabetes with his friends around and postpones most of his self-care activities, resulting in unstable BG numbers.

For Kevin, increased activity during summer camp and work, the food at summer camp, snacking at home, and presence of peers on weekends affected diabetes self-management. Figure 4 shows how these factors affected diabetes self - management in different frames that include Summer camp, Summer work, and Summer weekends. Kevin's schedule at the summer camp led to more activity and less time to manage diabetes. Kevin was also not sure about the carbohydrate counts in the camp food. All of this caused low BG numbers. The work days, that is the weekdays, after the camp concluded involved optimal activity and better eating schedule (less snacking) that resulted in stable BG numbers. On the weekends, he got very little physical activity and paid less attention to diabetes. Around friends, his adherence to self-care activities was lower than usual causing out of range BG numbers.

Role of Factors in Different Contextual Fames

The factors affecting diabetes management that emerged from our interviews include contextual factors (location, time, presence of people, and attitudes related to diabetes management) and clinical factors (food, insulin, physical activity, emotional state). These can be measured using phone or wearable sensors and self-reports, and hence, can be included in designing the logic of rule-based interventions, such as the Just-In-Time-Adaptive-Interventions [25]. Figure 5 shows different hashtags reported by participants during the diary study, representative of the factors we found in the interview data. By analyzing incidents from the frames described above, we found that certain factors were more

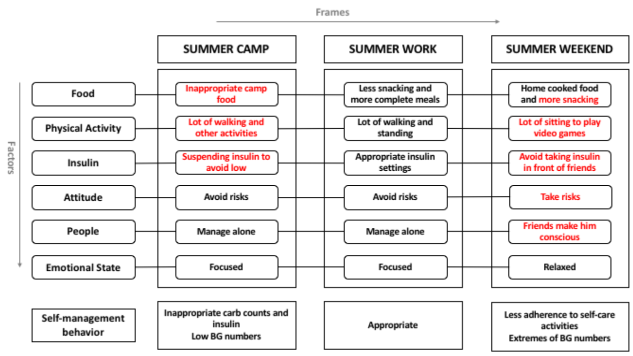


Figure 4: Kevin's contextual frames and factors

Table 2: Examples of hashtags and notes reported by P15 and P07 in different contextual frames.

Patient	Contextual Frame	Hashtags and Notes
P15	Grandma's Cottage	ate late due to traveling, #eat-inglate
P15	Home	#morninghighs, haven't tested for a while, only protein for breakfast
P07	Gym/Work	#lotsOfArms, #didConditioning, #gymnastics, #feltlow, #juice, #recheck
P07	Home	#high, #correction, #breakfast-beforegym, #ateat10

problematic or influential in some contextual frames than the others. That is, these factors had different impacts under different settings and the contextual frames described above help model these differences. Table 2 shows examples of hashtags and notes reported by two participants in different frames, further demonstrating the relative prevalence of factors. Next, we elaborate the role of individual factors to show how their influence changed across different contextual frames. We do not describe location and time in this section as they tend to be more tightly bound to the characterization of the contextual frames themselves, as noted previously.

Food. It was difficult to count carbohydrates when eating out (e.g., restaurant, friend's home, social event). For example, P01 spent weekends at church with a youth group where she ate from a buffet. This challenged her ability to estimate carbohydrates, leading to inaccurate amount of insulin, as described by her mother, *"if you have a buffet type-thing where you can keep going back up and getting more food she will but doesn't remember to shoot [take insulin] for it every time that she goes up there."* Similarly, in certain settings, participants made their own food choices in the absence of parental supervision resulting in unhealthy eating, as P02's mother described, *"He [P02] is much more likely to eat what we're having, if we're sitting at the table but when he comes home late he is looking into the fridge and maybe gets a little bit of that but doesn't choose the vegetables."* Thus, food as a factor was more likely to cause issues for diabetes management when away from home or when making choices independently.

Figure 5: A word cloud of the hashtags reported by participants representing a few contextual frames and several factors affecting diabetes self-management.

Physical activity . The role of physical activity as a factor affecting diabetes management varied between weekends and weekdays and also between seasons or days for participants who performed different activities during different seasons and/or on different days. For P12, who played soccer every day, physical activity influenced diabetes management more on the days when he had soccer tournaments (mostly weekends) than on a typical day of practice because on tournament days he played multiple games in a row, *"the difference isn't when he has soccer and when he doesn't, the difference is when he has a soccer tournament and when he doesn't. If he's playing two or three games in one day, we're in a whole different situation with him because of the intensity and the adrenaline and the hours of play at that point."* (P12's mother).

On the other hand, for P09, physical activity due to working in a restaurant was influential on weekdays but not on weekends as he was off work on weekends spending sedentary time at home. Similarly, P11 and P15 engaged in different activities (horseback riding, golf, dance, yoga) on different days of the week, which required adapting management based on how these activities affected them. P06 performed different types of physical activities in different seasons, which affected his diabetes management. Thus, the influence of physical activity (including exercise, sports, work, household chores, and other forms of activity) differed depending on the contextual frame (weekend versus weekday, different seasons).

Insulin . Different contextual frames required different insulin doses and these differences were less apparent at the time when they were decided on. For example, on work days, P02 ate a big dinner but this did not happen on non-work days. His insulin dose settings worked for days that he worked and ate more, but often did not work for non-work days because food and activity levels were different on such days, *"there might be a day where he doesn't work so he doesn't eat at night but then his basal and carb ratio is as if he did"* (P02's mother).

Similarly, P06 performed different activities in different seasons, which required him to use different insulin dose settings and administration. For example, while running in the summer, he did not use his pump for continuous administration of insulin but took a correction bolus after running while this was different for skiing during the winter season, *"Track is pretty much the same because he doesn't wear it when he runs. But for ski, he wears it. And I think in ski season he runs lower, like we've usually got to decrease his basal because he tends to run low when he skis"* (P06's mother).

Lack of activity for long durations, such as traveling in a car, required taking extra insulin. While the majority of the participants reported taking insulin reactively after being out of range because of a car ride, P12 did so pro-actively, *"on the pump, thirty minutes before the car ride I activate a temporary basal upwards of 30 percent so I'm getting my regular bolus - or basal, excuse me, plus a third of it. So that kinda keeps my sugar a little bit lower."* In summary, different contextual frames required different insulin intake or administration strategy depending on the other factors, such as food and physical activity, affecting diabetes.

Emotional state . Emotional state affected diabetes self- management mostly in relation to contextual frames other than home. For some participants, the transition from summer to school created stress, which affected their BG numbers. For example, P14 described stress as an important factor affecting her diabetes. She was stressed about school starting, *"Within the last week, I've been stressed mostly because thinking about school coming up. when I'm stressed, I either get very shaky and end up, my numbers being lower."*

Emotional state also affected self-care activities, such as healthy eating. P05's mother mentioned that P05 experienced extreme stress before going to see her father but did fine after coming back home, *"When she got diagnosed with diabetes, there was issues going on with her father. It was a big stressor. She would be super high just before she'd go visit him and then she'd come home and do better ."* In response to stress, P05 engaged in stress eating, *"I usually stress eat."* The above examples show that changes in contextual frames at times resulted in participants being less comfortable, increasing their stress and affecting management.

People . For most of the participants, weekends were associated with the presence of parents because of which diabetes management was better (e.g., getting reminders, making better food choices). However, for some participants (P01, P09), presence of friends resulted in poor management, which usually happened over weekends. For example, P09 did not want to pull out his pump or CGM when friends were around so he postponed the self-care activities, *"when I'm around a bunch of people I'm more cautious to pull out my pump to take insulin."*

In summary, presence of parents resulted in better management for some participants, which usually was the case for patients with stay at home mothers and on weekends for patients with working parents. Presence of friends resulted in poor management for a few participants.

Attitudes . Lastly, we also found that participants held different attitudes and personal preferences for diabetes management in different contextual frames, which determined their engagement with diabetes self-management. There was more risk mitigation involved on work days than when at home. For example, P04, like a few other participants (P02, P07), tested her BG numbers and ate before going to work so that she does not experience a low BG number, P04: *"I've started, like, checking before I go to work"*
P04's mother: *"We'll make sure she eats a meal or something before she goes".*

P09 and P06 took less insulin and more carbs before or during work, even though it would get their numbers out of range afterwards, but this was intentional and did not seem concerning, as described by P06's mother, *"sometimes if he's a work and he's low, he might think, 'Oh, I'm just going to eat a little extra because I don't want to deal with it taking too long to come up'."*

Traveling and vacation involved surrendering to mismanagement. For example, P08 mentioned accepting high BG numbers throughout the vacation and not paying much attention, *"It[travel and vacation] was a lot more insulin, a lot more carb, and some higher numbers. Pretty much throughout the entire trip I was high. I wasn't really paying attention to how I was feeling for being high."*
Thus, participants took control of diabetes to varying extents or let go entirely depending on the contextual frame in which they were managing diabetes.

5 DISCUSSION

In understanding the role of context on diabetes-self management, we observed that self-management varied across different high-level contextual settings (School, Home, Work, Travel, Summer, Weekends, and Weekdays), due to differences in the influence of factors (time, location, physical activity, food, emotional state, insulin, people, and attitudes) particular to those settings. To help explain how such influences on behavior vary with context, we introduced the notion of *contextual frames* as depictions of recurring contexts in which the factors that influence behavior and health status take on different degrees of relevance, thereby having different impacts on behavior.

Although the participants in our study were adolescents and their caregivers, the notion of contextual frames can provide value in the design of a range of other context-aware systems (e.g., personal assistants), including those intended to support the management of other chronic diseases for other age groups. For example, a working adult with Type 2 Diabetes might have their own (similar) set of contextual frames, such as work, home, out with friends, business travel, vacation, weekends, and weekdays, which would operate at different timescales, nest and overlap with each other, continuously transition, and associate with different factors and behaviors. The factors affecting adults could be different than those affecting adolescents. For example, working adults might not perform physical activity regularly or may not receive support from others (e.g., caregivers), making these factors less influential.

While many studies have reported how context affects the management of chronic conditions [1, 5, 8, 24, 42, 43], prior work has paid little attention to how such knowledge can be incorporated into the design of context-aware systems. The novelty of the work described in this paper lies in its focus on informing the design of context-aware systems by characterizing context-behavior relationships using contextual frames. Contextual frames allow designers to focus on collections of factors that need to be understood in relation to particular behaviors, and how these factors vary in their relationship to behavior over time.

For designers, choosing relevant factors from multiple contextual factors and alternatives for describing them (e.g., time and its description as seasons, years or days) is challenging [6]. Additionally, prior work does not provide guidance on how to explore various use cases around a set of factors relevant for a behavior. E.g., what is the influence of food and activity at work on insulin administration and how does that differ from their influence at home? Contextual frames provide a model to depict such differences and identify them from accounts of lived experiences. They provide a framework to systematically explore different factors to understand their prominence and select the most relevant ones. This can guide needs assessment and design choices for context-aware applications. In what follows, we elaborate the contribution of contextual frames in relation to context-aware system design.

Contextual Frames Relative to Different Perspectives on Context

Two perspectives on context have been described in the literature - phenomenological [14] and positivist [10]. Prior research has identified the need for high-level abstractions to make the role of context intelligible to designers, thereby providing translation between these two perspectives [2]. To this end, Dey et al. proposed *"Situations"* - an abstract representation to support intelligibility of context-aware applications [12]. In a similar direction, our work contributes *"contextual frames"* as a phenomenologically grounded abstraction of context to make the impact of context on self-management behavior intelligible and salient for the purpose of informing system design. Unlike Situations that require a knowledge of specific contextual features, contextual frames allow for a systematic exploration and discovery of key contextual features. While Situations expose the state of context in applications, contextual frames draw attention to the state of context in relation to a behavior. A Situation is defined in terms of highly specific rules based on context parameters. Contextual frames are not hard-coded rules but phenomenological abstractions to depict variety of potential configurations of contextual factors.

Contextual Frames to Model Context-Behavior Relationships

Contextual frames can guide designers as they explore the space of possible contextual features to include in their systems [6]. In this direction, we draw upon prior work on physical activity [22, 30] to demonstrate how contextual frames can be used to understand the likelihood of physical activity in different contextual frames of an individual's everyday life, as determined by certain factors that converge to affect physical activity in those frames.

Figure 6 shows examples of physical activity behavior of two hypothetical adults , Zain and Hana, in several frames including Work, Home after Work, and Weekends. In the case of Zain, the factors shown result in a high likelihood of physical activity in two frames - Home after Work and Work. For example, Zain has a dog to walk, which results in less effort involved in assuring that a walk would happen. However, in Hana's case, it is only on the weekends that these factors align to make physical activity highly likely. For example, absence of a walking buddy and facilities at work make it difficult for Hana to perform preferred physical activity on weekdays. As shown above, contextual frames can thus be used as blueprints to depict context-behavior relationships.

These relationships in turn can guide the conceptualization of context appropriate interventions.

Contextual frames can also help identify the relative prominence of contextual features among the many features that might be pertinent. For example, a factor might be a problem in one frame but not the others. Interventions can be tailored to support working with particular problematic factors, while being aware of the other factors in the frame. For example, in Hana's case, lack of company was a problem during the weekdays but not on weekends. An intervention can use a personal virtual coach or assistant to motivate Hana and give her company while she takes a walk after work.

6 DESIGN IMPLICATIONS

In this section, we provide design considerations for context-aware systems, that is design guidelines to tailor and contextualize support by using context. The design implications that we provide stem from the consideration of contextual frames as sensitizing concepts. Sensitizing concepts are "interpretative devices for the exploration of empirical instances and for abstracting their common features" [36]. They draw attention towards key aspects of a social situation that challenge design assumptions and lead to novel designs and interpretations. Contextual frames add value as sensitizing concepts because they provide abstract design knowledge, which can expose new and important design directions to explore.

Choosing Timescale Representations

Different contextual frames are associated with different timescales. Some recur with a more-or-less predefined schedule (e.g., work and school) while some are sporadic (e.g., travel). Similarly, transitions between frames unfold over large (e.g., summer and school) and small durations (e.g., weekends and weekdays). When designing a system that uses temporal context, designers need to ask what temporal cycles need to be supported and what representations of time need to be used. For example, time as a factor can be perceived as seasons, quarters, school and summer, weekday and weekends, day, weeks, months, years, and vacation, as described by our participants.

Identifying Couplings of Contextual Frames

In addition to recognizing the immediate contextual frame to make support context-aware, it is important to recognize meaningful sequences/couplings of contextual frames. This can be leveraged by anticipatory systems that predict context to identify the temporal ordering and prioritization of support for a behavior [31], specifically when different types of support can be provided in different settings. For instance, the current context being home and the predicted context being travel, the system could remind user to take extra insulin for the car ride before it begins.

Such sequences are also important for understanding the cumulative effect of preceding frames on the current and the subsequent frames. Similar to computational pipelines [9], the state produced by one setting becomes the starting condition or input to the subsequent setting. For example, managing with school-home-work in that sequence could be different from school-work-home. For adolescents, work right after school could mean managing without parental supervision for a longer time duration as opposed to work after home, resulting in higher likelihood of mismanagement. This might call for more persistent and proactive support for school-work-home sequence and more corrective management at home to fix what went wrong in the previous settings.

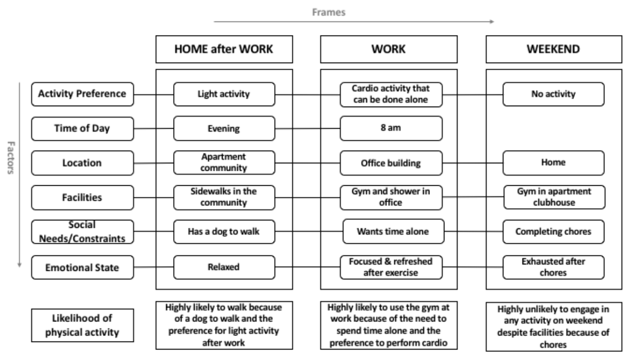
Leveraging Differences and Similarities Between Contextual Frames

Instances of patients comparing one contextual condition against another in our study demonstrate that the similarities and differences between these could be used to determine different support strategies. For example, if a new contextual frame is recognized by a system (say, *"summer day camp"*) and if it is very similar to an already existing and well understood frame (say, *"school"*) associated with a certain support strategy, the same strategy could be utilized in the new context with the likelihood of similar results. Hence, understanding the similarities and differences between contextual frames can inform decisions that designers might need to take when conceptualizing systems and interventions to align with multiple contextual frames.

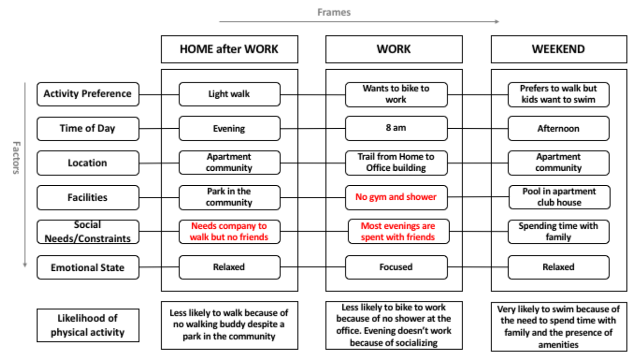
Our findings also show that the differences or similarities between nested/child frames might be a function of the broader/parent contextual frame. For example, as described in the findings, differences between weekday and weekends were more prominent in the school season than in the summer. These relationships can help identify the contextual features that should be considered in creating decision-rules for triggering interventions (e.g., just-in-time adaptive interventions [25]). For example, rules should not only consider *"type of day"* (weekday or weekend) as a temporal feature but also *"season"* (summer or school) as another temporal feature to reflect how these influence each other.

Choosing an Intervention Strategy

Our findings show that some behaviors might be confined to a single contextual frame while some might play out over multiple frames. For example, in Nick's vignette described above, the contextual frame of *work* triggers the behavior of eating a late dinner and the contextual frame of *home* is



(a) Zain's contextual frames and factors



(b) Hana's contextual frames and factors

Figure 6: Contextual frames showing factors affection physical activity and the likelihood of physical activity

where the undesirable behavior is performed and the consequence manifests. Such an understanding of behavior in relation with contextual frames brings forward the trade-offs involved in selecting the frames best suited for a specific intervention. Designers may ask which frame is best suited for a preventative intervention and which frame is best suited for a corrective intervention? For instance, an intervention trying to prevent a behavior from happening would be well suited for the frame where the behavioral trigger exists (work in the above example) and not where the consequences become observable.

The notion of contextual frames come with certain challenges that we wish to highlight. First, their abstract nature leaves them subject to interpretation, which could result in different implementations. Second, relying on automatic detection to identify contextual frames from sensed user data poses questions regarding the accuracy of detection. Incorrect frame detection could result in inappropriate system behavior that could mislead the users. Consequently, there would be a need to involve the users in understanding the correctness of automatic detection and navigating the trade-offs of incorrect detection. Third, user involvement further raises questions regarding how should frames be visually represented. These challenges offer new directions for research that future work should investigate.

7 CONCLUSION

Context-aware health self-management technology is promising owing to its capability to deliver support that aligns with the situated needs of users. However, including context in the design of systems to support a behavior is challenging as designers need to make multiple decisions (e.g., what contextual features are relevant for a behavior and how). To model context-behavior relationships for health self-management behavior, we introduce an abstract representation of context, which we call *contextual frames*, to denote the recurring and nested contexts in which certain factors influence self-management behavior with varying degrees of relevance. Our findings show how the role of the same factors changes across contextual frames, resulting in frames that have similarities and differences, which can be leveraged to provide different types of support in different settings. We demonstrate that while this concept is grounded in the self-management behavior of patients with Type 1 Diabetes, this can be translated to other behaviors, such as physical activity.

Our work contributes to the understanding of higher-level abstractions of context [12], to make apparent its role in influencing behavior and its role in designing to support the behavior. Additionally, it contributes design knowledge in the form of sensitizing concepts and practical guidelines for improving health-specific context-aware applications (e.g., JITAIs [25, 38], anticipatory systems [31]).

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