Assessing Asthma Management Practices Through In-Home Technology Probes

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***Abstract*— Asthma is a complex disorder and a leading chronic disease among children in USA. Families and pediatric patients with asthma need to manage different triggers and symptoms. We investigate existing asthma management practices and deploy technology probes to understand how they use technologies to manage asthma. The findings suggest that severity of asthma impacts the way that technologies are utilized. Thus, pervasive computing application can assist families and pediatric patients by bridging gaps between user's needs and their practices based on the severity of asthma and other contextual factors.**

Keywords-asthma; chronic disease; qualitative studies; technology probes; home

I. INTRODUCTION

Asthma is a complex disorder characterized by variable and recurring symptoms. It is a leading chronic illness among children in the United States; 5.6 million school-aged children and youth (5-17 years old) were reported to have asthma in 2007 [1]. It is a heterogeneous condition with triggers that vary between patients. The development of asthma involves the reciprocal action between host factors and environmental exposures. While there seems to be a genetic component, the definitive causes of asthma have not been established [2].

Interventions aimed at modifying the risk factors for asthma have determined that a multipronged and individually customized approach can improve treatment outcomes for asthma [3]. Use of an asthma counselor or case manager to deliver the intervention has emerged as a key component to implementing and delivering secondary asthma prevention measures. Programs that improve care, educate, control the exposure of children to allergens and irritants, and reduce exacerbation of symptoms decrease medical costs related to asthma. Appropriate case management and decreased exposure to environmental factors may reduce the frequency of acute exacerbations of asthma symptoms. However, not every family with asthmatic children is able to access these programs because they are a limited resource.

Pervasive computing applications are particularly well positioned to present a viable solution to this shortage. For instance, Intille et al. study two trends towards pervasive health care management [4]. The first trend depicts an environment with a wide deployment of computing devices to determine the communication capabilities of health information. Patients and caregivers use computing devices anywhere and, thus, have the potential to send or receive health information anytime. The second trend is a real-time context aware computing platform. A context-aware computer system can automatically infer what situation a person is in. These trends may enable technology to raise awareness and motivate management of asthma by providing contextual information to users. In particular, the relevant context includes the observed behaviors, the consequences of these behaviors, and the points of decision that trigger particular behaviors.

While the reality of pervasive healthcare management is more limited than what is envisioned by Intelli, we posit that in fact current technology can do much to facilitate disease management. Clark et al. have identified "self regulating behaviors" in asthmatic children and their caretakers. These regulating behaviors have been found to be predictive of important disease management outcomes such as increased quality of life and decreased use of emergency services. Self-regulating behaviors include being observant in regards to asthma symptoms and triggers and making judgements based on observations about asthma.

In this study, we seek to understand 1) current asthma management practices and 2) technology usage. We also discuss the role that technology can have in a disease management model [5].

Addressing these research questions requires mixed research methods. Qualitative interviews of individuals with asthma and caregivers and an observational study can result in rich insight into current asthma management practices. To investigate health-reasoning strategies and context, we created and deployed technology probes. The technology probes in this study are prototypes of potential applications [6]. The probes allow users to track personally relevant aspects of everyday life by providing visualization tools to interpret the datasets they collect. Typically, applications that monitor the context of the onset of a chronic outburst engage individuals and caregivers in reflective analysis [7]. Their goal is to minimize the onset of these outbursts by modifying the triggering behaviors. The probes in this study utilize sensing

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and self-report measurements to capture the patient's actions, daily trigger trends, symptoms, and daily peak flow meter readings [8].

The three main aspects of asthma management that emerged from the investigations are: 1) Being an observer and engaging in judgments, 2) Tractable management strategies based on the severity of asthma, and 3) Importance of reactions, namely the ability to make inferences about how to better manage asthma based on the data collected via the probes. We will explain these aspects in the discussion section.

II. RELATED WORK

An increasing prevalence of asthma and its associated morbidity resulted in pressure to encourage patients to become partners with health care providers in the management of their disease. Nearly three decades ago, a number of trends and forces converged, catalyzing the development of effective self-management intervention programs for individuals with asthma. The self-management concept was further advanced by the recognition and acknowledgement of the health management process as a shared responsibility. Researchers developed and tested a number of self-management techniques, further accumulating the body of experience and support for this treatment option [9].

However, promoting self-management is of little value, unless the relevant and necessary information reaches the individual and enables increased awareness and behavior change. Thus, understanding the health reasoning of individuals and caregivers is essential for the success of chronic self-care applications.

A. *Technology for Asthma Management*

One trend in intervention for asthma management has been to focus on technologies such as the Internet and cell phones to support self-reported diaries. A written diary typically includes subjective and objective assessments of the severity of the disease. Self-reported diaries are preferable to questionnaires or clinic-based consultations because accurate recall of symptom may be affected by memory bias. Hyland et al. reported, however, that symptom diaries of asthmatic patients are also inaccurate because they are typically based on retrospective recall [10]. The authors report that inaccurate diary entries produce incorrect medical prescriptions and instructions. They conclude that electronic-based diaries improve the quality of records.

Telemonitoring is another current trend in intervention for asthma management. Finkelstein et al. evaluated the validity of spirometry self-testing and assess the acceptance of an Internet-based home asthma telemonitoring system [11]. They deployed Internet-based telemonitoring systems at patients' homes for three weeks in a low-income inner city area. They found that spirometry self-testing can be valid in a group of patients with no computer background during telemonitoring. The results show higher patient compliance to asthma action plans in comparison to the compliance reported for patients in standard care .

Another study designed an Internet-based asthma self-management and education program to enable children to track their asthma symptoms and quality of life and to transmit this information to health care providers. Compared to individuals that used asthma diary, the individuals with the Internet-based system showed increased self-management skills and improve asthma outcomes [12]. A meta-analysis also found that patient knowledge and behavioral change outcomes are increased with Internet-based interventions as compared to outcomes from non-Internet-based interventions. The result depicts an improvement related to the participants' ability to acquire specified knowledge such as knowledge of asthma treatment [13].

However, technology based studies also have limitations. In one study, patients were given access to a web-based diary system that allowed them to monitor their asthama and to record their management strategies. In the diary, the patient entered peak flow values, number of doses of rescue medications, and other asthma related data. The system also gave patients feedbacks regarding their status. Health-care providers were given access to their patient diaries. Unfortunately, participants only used the system on a limitied bases. Researchers reported that patients did not fit the system into their everyday lives for a variety of technical and psychological reasons [14].

In an attempt to overcome the limitations of their first study, Anhøj and Møldrup investigated short message service (SMS) to support self-management of asthma [15]. Here the goal was to integrate the data recording into individuals daily routine. The result of this study showed that diary data collection via SMS is feasible, and that SMS may support the self-management of asthma because a cell phone, unlike the Internet, was a part of everyday life for the participants.

A standard tool for asthma management is a peak flow meter. This is a portable, inexpensive, hand-held device used to measure your ability to push air out of your lungs [16]. Asthma guidelines recommended peak exploratory flow (PEF) measurement to check the lung status of asthmatic patients. However the literature has mixed findings concerning the relevance of peak flow meter use for improved asthma status. One study indicated that using a peak flow meter without a system of self-management will be unlikely to improve patient care [17]. Another study shows that adherence to long term daily PEF measurement in the management of mild asthma in general practice does not appear to produce large changes in outcomes [18]. Yet another study suggested the poor correlation between peak flow meters and asthma management is related to the type of tool that was used. These researchers suggest that only electronic peak flow meters, rather than manual ones should be used for pediatric clinical trials [19].

Technology has also added to the discussion about the relevance of peak flow meter use. One study investigated peak expiratory flow (PEF) monitoring via SMS. This study concludes, "SMS is a convenient, reliable, affordable, and secure means of telemedicine that may improve asthma control when added to a written action plan and standard follow-up" [20]. In conclusion the literature review suggests that the combination of an Internet-based system and SMS

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data collection might be a more useful tool for patients than using only one technology. However, few studies investigate the combination of approaches [21].

B. Context for Asthma Management

Increasing concern over the effects of outdoor and indoor air quality on health exists in the scientific community. These concerns are even more pressing in the case of pediatric asthma. Thus, many studies investigate the role of air quality as an asthma trigger.

Sheppard et al. investigated the relationship between measured outdoor air quality in Seattle and nonelderly hospital admissions with a principal diagnosis of asthma. They found an increase in the rate of asthma-related hospital admissions associated with ambient pollutants [22]. Another study also looked at the association of outdoor air quality with the prevalence of chronic lower respiratory tract symptoms among children with a history of asthma. The result of the study suggests, "Children with a prior diagnosis of asthma are more likely to develop persistent lower respiratory tract symptoms when exposed to air pollution in Southern California" [23]. Interestingly, pediatric emergency room visits for asthma was reduced in Atlanta, Georgia, during the summers of 1993-1995 when traffic was reduced and outdoor air quality improved [24]. This study supports a relationship between air pollution and childhood asthma exacerbation.

Indoor air quality is also an important trigger for asthmatics. It impacts health from indoor exposure such as combustion products from heating, cooking, and the smoking of tobacco, and pollutants emitted from building materials [25]. Indoor air quality is closely linked to increased asthma prevalence. While the understanding of environmental influences is still relatively limited, indoor exposures may be more important than outdoor pollutants because children spend much more of their time indoors than outdoors [26]. Dekker et al. investigated the influence of indoor air quality on asthma. They verify that exposure to environmental tobacco smoke, living in damp houses, the use of gas for cooking, and the use of a humidifier are associated with childhood asthma [27]. Another study also reports results of an analysis of associations between indoor pollution and several outcomes of respiratory morbidity related to combustion sources [28]. Thus, it is crucial that technology interventions provide asthma patients with information regarding indoor air quality. Additionally, we need to investigate ways such context awareness impact their asthma management.

While these and many other studies inspired our work, the research questions regarding asthma management posited at the beginning remained unanswered. The findings presented in this paper extend the existing practices by investigating asthma management strategies, symptom reasoning involved in the management, and the limitations of the current practices.

III. METHOD

The research community has long realized the importance of an understanding of an individual's everyday life. Due to privacy and other sensitive issues of ethnography, a new set of techniques such as technology probes have emerged [6]. The goal of the technology probes is to investigate the needs and desires of participants in a real-world setting, and test initial prototypes.

In the current work, one of the main research goals was to use technology to understand how patients and their caregivers reason in regards to the asthma symptoms and triggers. Thus, we designed our probes to provide context and engage families and pediatric patients in reasoning about their asthma symptoms, triggers, and perception. Here, our probes were developed as a means of gathering information such as user requirements and needs [29]. The information we gathered is about understanding real-world setting and potential new applications for pediatric asthma management.

A. Technology Probes

We designed the probes to support raising awareness of the pediatric patient's health behavior, triggers, and other contexts in a reflective manner. The probes also served an early prototype of an asthma management system that allows users to record sensing data and daily activities. This is information that augments traditional asthma diaries. Our probes specifications are described below. All components of the probe were from commercially available products except for the web based tool, Salud!, and the multifunction widget (see Fig. 1).

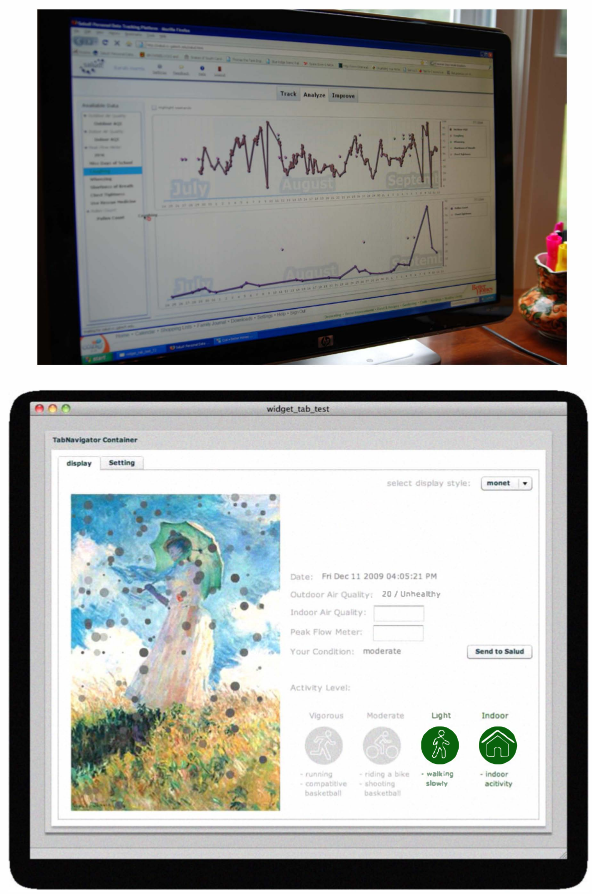

Figure 1. Salud! application (Top) can displays data collected from a variety of sources over the same period of time. This allows participants to reflect on the relationship between the data that is collected and their asthma status. Multifunction widget : Monet view (Bottom)

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1) Temporal data management application

We provided participants with a web application called Salud!, an online system for tracking and reviewing everyday activities [30]. Participants were able to use Salud! to record and annotate events using a variety of methods. This included cell phone text to a dedicated telephone number and a web-based interface. The cell phone messages were processed automatically, without human intervention. The data could then be reviewed and visualized using an online web application. The visualization tools included basic charts, graphs, and other summary views. Salud! came with a variety of event data templates (e.g., the measurement of peak flow, air quality index, meal times, and daily stress self-reports) that users could begin using immediately. We also created a pre-defined set of logbooks for children with asthma. However, users were also able to define and create logbooks that they would like to track. Salud! relied on the user to input any information—it did not record any information without users' knowledge. Salud! did not present any automatically derived conclusions, or make any recommendations to the users.

2) The peak flow meter

We provided participants with a digital peak flow meter (Piko-1), and asked the mother to help manage the data from their child's peak flow readings. The children could also use short message service (SMS) to enter the peak flow measurement into the Salud! application.

3) The indoor air quality sensor

We also provided participants with an air quality sensor (ET-4) in their home. This air quality sensor monitored indoor air quality on a scale of 0 (good) to 1024 (bad). The unit measured many different airborne particles, such as pollen, dust and other air particulates.

4) Multifunction widget

We offered participants a widget that could be installed on their computer. The widget enabled users to look at outdoor air quality index based on the ZIP code of their home and recorded these values into Salud! every hour. A user could enter values of indoor air quality and peak flow meter derived from provided devices into the Salud! application via the widget. The widget showed appropriate activity level by adapting Asthma Slide Rule, which determined outdoor activity level based on patients' current asthma condition and outdoor air quality [31]. The widget included two visualization modes. The first one was a Monet view (see Fig. 1), and another one was a Circle view. The number of moving circles was correlated with the current harmful air quality in both views.

B. Deployment study

Our probes were deployed in three households for four to six weeks each. The participants for this study were recruited via recommendation of physician and Craigslist, a centralized network of online communities. Participants were children with a clinical diagnoses of asthma and one of their parents (see Table 1). Participants were required to have regular access to a computer and Internet access.

TABLE I. PARTICIPANT DEMOGRAPHICS

Participants (Ethnicity/Income)	***Child's Asthma Severity***	***Participants*** ***Mother (Marital status, Age/Occupation / Education level) Child (Sex/Age)***
Family1 (Caucasian/25,000~50,000)	Moderate	Married/29/ Homemaker / College
		Girl (7)
Family2 (African American/75,000~100,000)	Mild	Married/34/Nurse / High School)
		Girl (16)
Family3 (African American/50,000~75,000)	Intermitent	Married/43: Realtor / College)
		Boy (12)

Each of the participants including the child with asthma was scheduled for an introductory, 60-minute interview. During this meeting we administered the consent form, conducted a semi-structured interview and assigned them an account on Salud!. We also provided them with a tutorial on how to use the peak flow meter, the air quality sensor information and various features of Salud!. However, we did not urge them to use the technologies we provided. We collected basic demographic information (gender, age, level of education, and occupation) and administered the Pediatric Asthma Quality of Life Questionnaire (AQLQ) a well-established indicator of health-related quality of life [32]. Participants also drew a sketch with the various factors that impacted their asthma management.

During the study period we also had weekly follow up interviews with the participants over the phone. The final, interview occurred at the end of the deployment period in their home. All participants filled out a Pediatric AQLQ again. Additionally, we asked participants to reflect on the entire deployment period and discuss any effects they perceived, as well as present a sketch of their asthma management before and after the study. This sketching activity allowed for active involvement of the users in the very early stages of ideation and exploration. The approach provided a rich medium for discovery and communication of design ideas [33]. All the sessions were audio recorded, transcribed, and analyzed. We use pseudonyms for the participants' in the case-studies.

IV. FINDINGS

In this section we discuss the interview findings. We also provide analyses probe deployment case-studies to address current 1) asthma management practices and 2) technology usage.

A. Understanding current asthma management

Here we report the effect that patient variables (e.g., age and asthma severity) and caretaker variables (e.g., occupation and income) have on asthma management.

1) Family 1 - moderate asthma

Susan is a 32-year-old homemaker with two children. Erika, the 7-year-old daughter was in our study. Although Erika has a diagnoses of moderate asthma Susan reports that that the hardship of managing Erika's asthma led her to quit her job. Susan reported that Erica had been diagnosed as having a bronchial disorder by her pediatrician. However over

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her life this condition got more severe and it was in the last 3 months that the pediatric pulmonologist gave her a diagnoses of asthma.

Susan usually finds relevant information through the Mothers of Asthmatics website and a healthy home checklist. Susan reports that she has tried to figure out what Erika's asthma triggers are. She thought that both allergies and physical activity caused Erika to experience asthma symptoms. However, Susan did not have specific examples from her environment to support her intuition.

Susan reported that the information she gathered related to potential asthma triggers made her changed her lifestyle. One of the things that Susan changed after having been to the pulmonologist was her housekeeping practices. She stopped cleaning with commercial cleaners. Now she cleans with baking soda and vinegar. She also washes everything in hot water. She vacuums all of the furniture once a week and vacuums the carpet twice a week. To reduce allergens, Susan bought an air purifier that her pulmonologist recommended. However, she was not confident that this was helpful.

Susan noted that the work load associated with managing Erika's asthma was intense and that she did not think she would be able to maintain it if she was working. Susan had been concerned about Erika's school environment. She noted that cockroaches are an issue because Erika was allergic to them. Susan thought that she could control domestic environmental factors as well as behavior that negatively affect Erika's asthma status (i.e. dust, dirty carpet,, germs). However, she did not feel the same was true when Erica was at school. For example, she noted that she could not control what Erika did during recess.

Susan had taken a systematic approach to managing her daughters asthma. She reported that she would write down a given goal and then she would write down the steps that she needed to take in order to meet the goal. Susan was using a web-based journal and Excel to do this.

2) *Family 2 - mild Asthma*

The second participant, Julie, was a 34-year-old nurse. Her 16-year-old daughter, Monica, was only diagnosed eight month prior to the study.

Monica's asthma was mild. However, because of the recent diagnosis they were still trying to find possible triggers. Julie gathered information about asthma through online sources. Julie also had nutritional books that she used as references to manage Monica's asthma. Since Julie was working for a doctor's office she also collected information from her colleagues.

Julie tried to manage Monica's asthma with diet and supplements (not medication) through trial and error. For example, early on they suspected ice cream as one potential trigger but since then they had realized it did not really impact Monica. They had an air purifier in Monica's room since they thought indoor air quality was important for Monica's symptoms. Julie reported that her ability to manage Monica's asthma, was sometimes impeded by her job. She sometimes had to work nights and thus could not manage Monica's diet.

Monica was an adolescent that took charge of monitoring her asthma status. Monica was knowledgeable about her symptoms and triggers, and read books related to asthma. However, Monica sometimes did not like to share her asthma status with her mother because Monica did not want her mother to "nag" her. She wanted to be independent.

3) *Family 3 – intermittent asthma*

The third participant, Natalie, was a 43-year-old realtor. She usually worked at home on the computer. Her 12-year-old son, Mike, has asthma. He was diagnosed as a 3-years-old.

Mike's asthma was under control and he only had intermittent flare ups. Due to the status of Mike's asthma, Natalie spent much less effort in managing her child's asthma than other participants. She typically focused on medication and did not pay attention to possible triggers (i.e., environmental factors). Like Monica, Mike was knowledgeable about his symptoms and triggers and was in charge of taking his medication when required.

B. *Understanding technology usage*

The technology usage among the three families was variable. The use of the probes increased their observations and influenced their judgments and reactions.

1) *Family 1 – moderate asthma*

Susan used the probes continuously during the deployment period. She created an additional logbook in Salud! to record pollen counts since Erika had pollen allergies as well. Susan encouraged Erika to use the peak flow meter at least twice a day. Susan put the indoor air quality sensor near the desktop in living room. Whenever Susan used her desktop, she checked the widget to find out outdoor air quality and the indoor air quality. Since Susan already kept family record in an online journal, she felt that using a computer to enter data was not overly demanding.

Based on the measurements of peak flow meter, Susan tried to find out which triggers affect Erika's symptoms. The data collection led her to believe that outdoor air quality affected Erika's status. However, she could not find any other correlations. She even created the pollen counts logbook. In terms of the indoor air quality probe, she found the sensor was not sensitive enough to register immediate changes in the environment. Thus, she could not determine what caused the change of indoor air quality measures.

After using the probes, Susan discovered that outdoor air quality was an asthma trigger. She then tried to reduce Erika's physical activity when she saw high index of bad outdoor air quality. Although the indoor air quality sensor was not sensitive enough to detect major changes in the environment, Susan opened windows when she cooked or vacuumed.

Susan enjoyed Salud! so much that she decided to keep records in Salud! even after the deployment ended and Erika was back in school . However, tracking Erika's symptoms was much more difficult then it had been during the summer because Erika did not tell her mother everything she did in school. Interestingly, Susan's drive to collect data in Salud! led her to conversations with Susan that indicated that physical

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exercise exacerbated Erika's asthma symptoms (i.e., her symptoms were worse on days that she had gym).

2) Family 2 – mild asthma

For the deployment, we asked Julie to install the widget. However, Julie did not want any desktop application installed on her computer because of privacy concerns. Julie agreed to access Salud! since she thought Salud! is safe because it is a web-based application.

During the deployment, Julie thought that her daughter Monica could take care of herself and so chose not to use any of the system's features other than the air quality sensor. Thus, Julie did not know how many symptoms Monica had and what Monica found in terms of triggers. Monica, on the other hand, was very involved with the system. Even though we did not provide the widget, Monica accessed a web page that showed outdoor air quality and recorded these values in Salud!. Despite her mother's objections, Monica wanted the widget because it was tedious to access the web page to have information whenever she used Salud!.

By using the system Monica was able to dispel her belief that indoor and outdoor air quality negatively impacted her asthma status. She also noted that because she was able to record all of her symptoms she was actually more aware of them.

Julie reported that she was happy with the system since she could persuade Monica to do the right things based on the values Monica entered. She also reported that one of the advantage of the probes was that it helped her visualize things that are otherwise invisible. For example, the peak flow meter, gave her a sense of how Monica's lungs were doing. Likewise, the air quality sensor provided them with data they could not ascertain by just looking out the window.

They did not report any disadvantages in using the technology. They thought more information was always better unless the data was faulty.

3) Family 3 – intermittent asthma

After using the probes, Natalie did not try to find any relationship between triggers and symptoms because Mike did not have any flare ups during the deployment period. She also did not change her lifestyle much. In the first few days of the study, she recorded peak flow meter and indoor air quality measurements. After that, she did not use Salud! and the peak flow meter anymore. However, she was still looking at the indoor air quality sensor and the widget when she started to work at home. She reported that although she trusted Mike she was still generally concerned about whether he was taking the medication properly. After the study, she wanted to keep the indoor air quality sensor to manage her house's air quality.

C. Results

According to the sketching activity, Family 1 reduced the number of factors they had to manage. Family 2 reported that after having the probes their asthma management became more constant than before the probes study. Table 2 shows the number of recorded logbooks during the deployment. Once again, severity of asthma impacted the data we found. Family 1, who had the most severe asthma status entered more logbooks in an attempt to find the relationship between triggers and symptoms. The last family was symptom free and did not use Salud! at all.

TABLE II. THE NUMBER OF RECORDED LOGBOOKS

	Participant (The number of days of deployment)		
Logbooks	*Family1 (44)*	*Family2 (28)*	*Family3t (32)*
Chest Tightness	4	0	0
Coughing	12	3	0
Indoor Air Qaulity	73	11	3
Miss Days of School	0	0	1
Outdoor Air Quality	465	9 (Manual)	190
Peak Flow Meter	62	11	2
Shortness of Breath	7	0	0
Use Rescue Medicine	5	0	0
Wheezing	0	3	0
Pollen Count	26	N/A	N/A
Total logs per day	**15.86**	**.84**	**4.45**
Manual logs per day	**4.30**	**.84**	**.14**

All participants reported an improved quality of life after using the probes. This is interesting given that 2 of the 3 families only used the probes on a limited basis (Fig. 2). Data also indicated that the severity level of the child's asthma also had a large impact on the quality of life of the family. Family 1 reported the lowest quality of life and had the most severe case of asthma. The other two families reported similarly high scores at both pre and post visits.

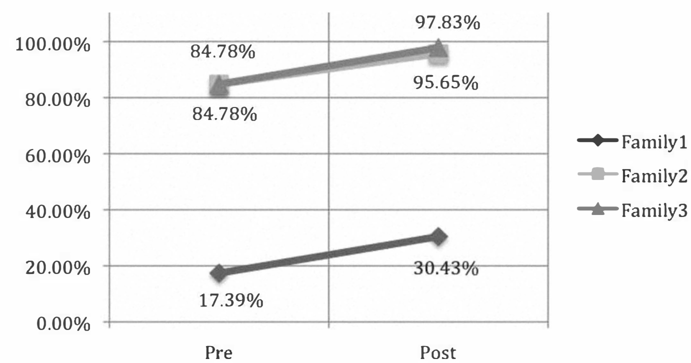

Figure 2. Pre-post AQLQ percentile scores for each families

V. DISCUSSION

In this section we will outline the main findings and how they relate to different aspects of asthma management. We will also discuss a number of directions for the design of pervasive computing applications based on Clarke's model of disease management. This will help us illustrate how technology can aid individuals in bridging their understanding between triggers and symptoms.

Clark et al's model of disease management suggests that an important aspect of controlling asthma is the patient conscious use of strategies to manipulate situations to reduce the impact of disease on daily life. They add that one learns which strategies do or do not work through processes of self-regulation and that a person is motivated to be self-regulating

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by a desired goal or end point. They state, "Being self-regulating means being observant and making judgments based on observation (versus habit, fear, tradition, etc.). It entails reacting appropriately to achievement of the personal goal when attempting to change one's own behavior." [5] This model highlights the obstacles in the current practices. It also provides opportunities to improve current practices and suggests three self-regulation elements that can be facilitated with pervasive computing applications.

A. *Emerging aspects of asthma management*

1) *Being an observer and engaging in judgements*

The main goal of all asthma management activities is to reduce symptoms and avoid hospitalization. The management techniques usually include taking appropriate medications at appropriate times and avoiding triggers. While the Guidelines for the Diagnosis and Management of Asthma (NIH guidlines) provides regimens [2], developing a customized management strategy is still a challenge for families and pediatric patients with asthma.

Due to the heterogeneity of asthma, physicians are not able to provide detailed guidelines concerning the triggers that impact the individual. Thus, families and individuals with asthma need to proactively analyze the relationships between contexts and outbursts.

2) *Tractable management strategies based on on the severity of asthma*

Families and newly diagnosed pediatric patients have a hard time figuring out which triggers affect their asthma. It takes time to establish strategies for asthma management. However, it is critical that they find triggers as soon as possible because even a single episode can lead to the patients' death.

According to NIH guidelines, physicians adjust patients' therapy based on the severity of the condition. Similarly, intervening technologies should actively adjust to the evolving severity of the condition for each patient.

3) *Importance of reactions*

All participants tried to reduce or avoid triggers. For example, cleaning their home frequently, using alternatives to chemical cleaners, and changing physical activities were among the most common actions reported by our participants.

However, unlike other chronic conditions, many critical asthma triggers are typically outside the control of the patient, for instance, pollen count and pollution. This difficulty of asthma management often results in patients ignoring triggers, ultimately leading to a complete abandonment of their asthma regimen. Thus, technology can provide information about triggers and allow individuals make observations and judgments that lead to appropriate reactions. Reactions include parents confidence level related to preventing their child from getting triggers and symptoms, and how parents know specific disease management to control triggers and symptoms.

B. *How can technology intervention assist individuals in managing their asthma?*

1) *Asthma Severity*

The severity of asthma impacts observations, judgments, and reactions. If pediatric patients have a mild or intermittent condition, they do not need to make observation frequently and there are no triggers to monitor regularly. However, they still need a place to register their observations concerning their symptoms. This may be the case to prevent exacerbations and adequately take their medication. Thus, technology can facilitate these goals and for example, provide reminders to take medication or it may provide a way to support judgments and reactions via a digital asthma diary that can later be "mined" to find low frequency triggers (i.e. seasonal asthma attacks). Likewise if the sensor data is readily available it can automatically log environmental data (e.g. seasonal changes in humidity or air quality) that might be associated with the flare-ups.

Severe and moderate conditions mean having symptoms almost daily. Pervasive applications are especially important in this context. The emerging sensor networks and the support of citizen science [34] can help individuals keep track of triggers that might affect symptoms. However, the communication gap between parents and children can negatively impact the accuracy of observations and delay finding triggers. Thus, a capture and access service can bridge this gap and help to identify triggers. For example, in our study we found that the temporal data management application helped one family identify relevant observations. Here the parent was able to map an external context (e.g. school schedule) and activity (e.g. physical exercise) to an increase in asthma symptoms.

The temporal data management application coupled with machine learning and data analysis can support judgments and reactions as well. Since they had to manage a number of data sources, sometime it is tedious to look at visualization to find correlations between triggers and symptoms. Thus, inference algorithm might help them to reduce the load and actually suggest data trends that are related to asthma symptoms.

Data logging activity itself can also raise the awareness of symptoms. For example, one of the pediatric participants reported that using the probes helped her realized that in the past she was actually ignoring her symptoms. She reported that once she became aware of her symptoms (because of data entry into Salud!) she was more motivated to take her supplements.

C. *What is the necessary and sufficient level of technological support to provide an adequate management solution?*

Reaching patients' management goals is important; however, we should consider a balance against the disadvantages of observations, judgments, and reaction, such as participant's perceptions, technologies' inconvenience and costs.

First, we should be careful in our choice of sensors since their accuracy can affect the patient's observations. In the worse case they could lead to inappropriate judgements and

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http://dx.doi.org/10.4108/ICST.PERVASIVEHEALTH2010.8839

reactions. In this study, the indoor air quality sensors were not sensitive enough to detect major environmental changes such as cooking or vacuuming. The participant simply ignored the sensor reading (that no deleterious effect in air quality was monitored) and open the windows anyway. However, if someone followed the sensors blindly then the negative air quality could have negatively impacted the patient.

Second, we should consider privacy issues in developing applications. This is not only about data security but also how participants perceive security. For example, one of the parents did not allow us to install the widget because she did not trust them. She placed a higher value in web applications even though there is no difference, in terms of intrusiveness, between desktop-based and web-based applications. Thus, we should be careful in deciding what platform to implement our applications.

Third, novel interventions might not be used by patients with intermittent and mild asthma conditions. This would negate the need to develop technology for data that is readily available on line i.e., air quality and pollen counts.

Fourth, we should not overrate existing technologies. For example, we built in a feature that allowed individuals to use their cell phone to enter data into our system. However, no participants in our study did this. This was the case because two children did not have their own phones and the other did not use the peak flow meter. Thus, we should investigate and understand the target population's practices before introducing technological features.

VI. Conclusion and Future Work

In this paper we discussed opportunities to improve asthma management by applying two method: qualitative interviews and technology probes. This study described the need for parents and patients to observe and engage in judgments to control their asthma symptoms and triggers. Understanding the consequences of context allows tractable management which leads to changes in confidence levels and sense of control.

In this study we found that the level of technological support should change based on the patient's disease severity. Our findings also highlight a number of possible opportunities for improving pediatric asthma management. While our investigation shed light on our initial research questions they uncovered many new ones. Based on our current findings, we plan to build and test a system that has features that can be adapted to take into account the severity of the child's asthma. And that can also be individualized to the family's technological practices.

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