Reflecting on Pills and Phone Use: Supporting Awareness of Functional Abilities for Older Adults

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ABSTRACT
Older adults often struggle with maintaining self-aware of their ability to carry out everyday activities important for independence. Unobtrusive sensors embedded in the home can monitor how older adults interact with objects around the home and can provide objective accounts of behaviors to support self-awareness. In this paper, we describe the design and four month deployment of a prototype sensing system that tracks medication taking and phone use in the homes of two older adults. We describe two case studies on 1) how they engaged with the data by looking for and explaining their own anomalous behaviors and 2) how they used the sensor data to reflect on their actions and their own self-awareness of their abilities to remain independent. Finally, we propose recommendations for the design of home sensing systems that support awareness of functional abilities for older adults using reflection.

Author Keywords
Older adults, reflection, awareness, functional ability, aging-in-place, embedded assessment.

ACM Classification Keywords
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General Terms
Human Factors, Design.

INTRODUCTION

Many older adults strive to age in place, in the familiar setting of their own homes. As they age, older adults often experience subtle changes in their cognitive and physical abilities [1]. These changes manifest themselves as changes in their functional abilities, that is, how well they are able to carry out everyday activities such as taking medication, managing their finances, preparing a meal, or using the telephone.

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However, many older adults have difficulty noticing and keeping track of these subtle changes in their functional abilities [19] and thus are unable to make the appropriate adaptations to compensate. As a result, this lack of awareness can lead to a pattern of repeated errors [6] such as taking the wrong medications, misdialing the telephone, and using kitchen appliances in unsafe ways. Not only can these errors be a hazard to safety, they can also be early signs of pathology such as Alzheimer's disease, Parkinson's disease, or other progressive neurodegenerative diseases that are considered most treatable in their early stages [12]. Often the impetus for having an individual screened for these conditions are when family members notice an unusual decline in functional abilities. Older adults, particularly those who live alone or have infrequent contact with others, can benefit from a means to stay more self-aware of the functional changes they are going through so that they are able to make the appropriate self-adaptations to continue to age in place gracefully.

Home sensing technology, or sometimes called embedded assessment technology, to monitor the well-being of older adults is a growing research area in human-computer interaction. Sensors can track how people move around in the home [2] and perform household activities [16,23]. Many of these research efforts focused on detecting problems and offering assistance to help correct them. In contrast, the focus of this work is how similar home sensing technology (and the data they collect) can be applied to provide timely and objective cues for older adults to reflect on their abilities as they age. Home sensing systems, like many ubiquitous or embedded sensing systems, can collect an overwhelming amount of data, particularly for older adults who may not be familiar with the types of detailed data that sensors can collect. Understanding what information older adults look for and then how to present this information can help designers refine home sensing systems to support reflection.

In this paper, we present a prototype home sensing system that monitors two tasks important for independence, medication taking and telephone use. We describe qualitative case studies of two older adults and how they used the data collected about their own behaviors over four months to investigate and reflect on their abilities to maintain independence. From these case studies, we provide design recommendations on how to present personal data from home sensing systems to support reflection and sensemaking for older adults to increase awareness of their functional abilities as they age.

RELATED WORK

Embedded assessment, the concept of using embedded sensors in the home to monitor the functional abilities of older adults, was introduced by Morris *et al.*, [18] and later discussed at a CHI workshop [17]. They envisioned systems that could automatically collect data to assess wellbeing, detect disease earlier, and facilitate informal caregiving. One of the main HCI challenges identified in the workshop is in understanding how to support individuals who want to manage their own health with the data collected from these systems. Since the concept was introduced, technology has made possible the development and testing of a number of prototypes of embedded assessment systems with real users, including TigerPlace [21] and EliteCare [10]. Both TigerPlace and EliteCare are independent-living facilities that use sensors such as motion and bed sensors to monitor the activities and ensure the safety of its residents. Our sensing approach is to monitor specific tasks such as medication taking and phone use that may provide earlier and more sensitive signs of cognitive or functional decline rather than overall activity levels.

In addition to research on technical systems for monitoring health in the home, there has been research in the CHI community investigating how older adults and people with chronic conditions manage their health in their everyday lives. Birnholtz & Jones-Round [3] investigated the tensions between older adults' need for security and their desire for independence. Ballegaard *et al.* [1] called for designers to not only take a clinical-centric view of health technologies but also to consider the needs of the patient and the everyday contexts in which technologies are used for self-learning. We adopt a similar non-clinical, user-centered perspective in this paper to understand the unique needs of older adults and how they make use of sensor data about their functional abilities.

We investigate how older adults use sensor data to support reflection on their own health. Li *et al.* [13] discuss a framework for how users deal with information collected about themselves (such as how they carry out everyday activities). We analyze the *reflection* and *action* stages of that framework from the perspective of the older adult for this paper. Reflection has shown to be effective for people with diabetes, for improving their sense of control and improved diet outcomes [15]. Reflection and the ensuing awareness of healthy and unhealthy behaviors for cardiac rehabilitation patients were found to be important for successful recovery [14]. In this paper, we conduct two case studies to investigate how older adults used data about how they perform everyday activities important for independence to become more aware of their abilities as they age, through reflection. Our case studies focus on the following three research questions:

1. How do older adults engage with and reflect on embedded assessment data?

2. Does reflection on embedded assessment data help older adults have a more accurate awareness of their abilities?

3. If reflection is helpful, how do we support reflection on the performance of everyday tasks important for independence to increase awareness?

In the following section, we describe our prototype sensing system and the tasks that it monitors.

SENSING SYSTEM DESIGN

We developed prototypes of a sensing system designed to monitor different activities that are important for independence and commonly used in clinical assessments [11] and deployed the system in the homes of two older adults for about six months. Our system unobtrusively and automatically monitored two everyday activities: medication/pill taking and phone use. Both sets of sensors transmitted their data wirelessly in real time to a research laptop placed out of sight behind a couch. The laptop logged the data and uploaded it every night through a modem connection to a campus server.

To monitor the pill-taking task, we developed a smart pillbox (Figure 1) that could monitor when a door was opened and how the box was manipulated. We augmented an existing off-the-shelf pillbox with snap action switches to know which doors were open. The design is similar to the MedTracker prototype [8], but our design adds an accelerometer that can monitor how individuals handled the pillbox and whether the pillbox was inverted (a common strategy to remove the pills because older adults' finger often do not comfortably fit inside the box). The electronics, including a microcontroller, a ZigBee wireless card, and a battery, are mounted in an adjacent compartment (actually a second pillbox with the dividers removed). The resulting smart pillbox is easily grasped and has an appearance nearly identical to that of a non-augmented pillbox.

Figure 1. The smart pillbox uses snap action switches to detect when doors are opened and closed. An accelerometer tracks how the box is held, shaken, or inverted.

To monitor phone use, we developed a custom circuit that we connected directly to the phone line. The circuit uses a Mitel MT8870 DTMF decoding chip to monitor what numbers are dialed, whether the phone is on or off the hook, and the length of phone calls. A computer modem monitored incoming calls and Caller ID. Both the phone sensor and modem were "invisible" in their operation to the user, as they did not affect the users' calls.

Sensing System Deployment

We deployed the smart pillbox and phone sensors for six months in the apartments of two older adults who lived alone. We replaced their pillbox with our instrumented pillbox that had the exact same size, lettering, and shape as their existing pillbox. We encouraged participants to carry on as normal and avoid being extra careful just because their activity was being tracked.

In the first two months, we continually revised and reintroduced more robust versions of the sensors, which left us with approximately four months of valid pill-taking and phone use data. Throughout the deployment, a researcher visited the apartments every two weeks to replace batteries, debug sensors, and ensure that the sensors were not getting in the participant's way. We verified the accuracy of the sensors through a combination of lab testing, field testing, and observations of use during bi-weekly visits to the apartments. On a few occasions we were unable to collect data for one or more consecutive days due to a power loss or error in the logging script. In the four months (122 days) of data, there were 15 unlogged days for Participant 1 and 16 unlogged days for Participant 2.

Case Study Participants

We recruited two older women who lived alone in their apartments through a professional connection with the management of a low-income senior apartment building. These two individuals represent a population that may benefit the most from monitoring technologies as they lack care support from a spouse or a daily caregiver. Both have an adult child who lives within an hour's drive.

Participant #1 (P1) (age 81) is a retired nurse, who is aging successfully. P1 has set in place the routines that ensure her safety in her medication taking. She prides herself in keeping up to date with the latest news and politics and overall has a generally accurate impression of her own abilities. She has mobility issues that make it difficult for her to walk up and down stairs and for long distances. Based on psychometric testing (Computer Assessment of Mild Cognitive Impairment) [22], P1 exhibits a slightly higher level of ability in attention, memory, and executive functioning compared to her peers.

Participant #2 (P2) (age 77) is an older adult who once struggled with moderate symptoms of Parkinson's disease. The disease once took away P2's ability to concentrate and control her limbs. However, she has recently started to take medication that was effective at eliminating most of her Parkinson's symptoms, resulting in her being able to walk, write, and concentrate moderately well. She admits to having a memory problem due to the lingering symptoms of the disease, but generally believes that she is pretty aware and aging well. She also does not consider herself to be an organized person, preferring clutter to putting things away. Based on psychometric testing [22], P2 exhibits a lower level of cognitive ability across attention, memory, and executive functioning compared to her peers.

After using the final version of the sensors for four months without seeing the data, each participant was presented with visualizations of data showing their own pill taking and phone use behaviors. We chose to withhold the data during the sensor deployment so the sensors could capture the participants' natural behaviors without the influence of feedback from the system.

CASE STUDY INTERVIEWS

We conducted qualitative semi-structured interview sessions with each participant in which we showed them data about their pill taking and phone use tasks to allow them to reflect on their own abilities to stay independent. The interview consisted of a researcher-guided training phase (to ensure the participants could understand the visualizations) followed by a participant-guided exploration phase. In the training phase, the researcher first showed the participant visualizations of data from a short time frame (for example, from the day or week immediately preceding the interview) and then explained what the marks, axes, and dimensions represented. The researcher refrained from making any interpretations of the data (*e.g.*, "you made a mistake here" or "you missed your pills a lot in the past month"). The researcher then tested the participant's understanding by having her describe a visualization of another day's data.

After adequately demonstrating their comprehension, the participant was allowed to guide what level of detail of the data they wanted to see. We used a think-aloud study protocol to allow the participant to express her thoughts and reflections during the interview. To understand any change in awareness, the researcher asked the participant to assess her own pill taking and phone use abilities before and after looking at the data. To understand the participant's intent for future actions, the researcher also asked questions such as "Would you do anything differently because of what you are seeing, or not?" The interviews were video recorded. The video was segmented into units of analysis that consisted of a participant's single thought or stream of related thoughts. These segments were analyzed using Grounded Theory [7] where coded segments were grouped into successively higher order categories resulting in emergent themes. In the following sections, we describe the data visualizations and the results of the analysis.

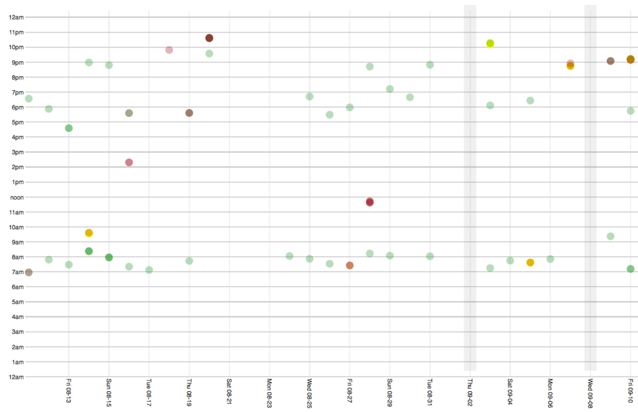

Figure 2. Long-term visualization of pill taking. The y-axis is the time of day, and the x-axis is the date. A green dot represents opening and closing a door that matches the day of the week. A red dot represents when the door does not match the current day of the week. A yellow dot indicates the door was not closed.

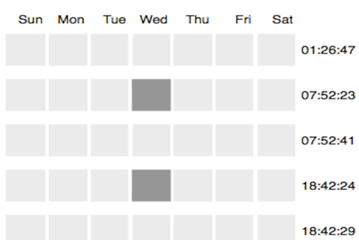

Figure 3. Short-term pill taking visualization showing pillbox door states and times for a particular day. The user opened and closed the Wed door in the morning and in the evening.

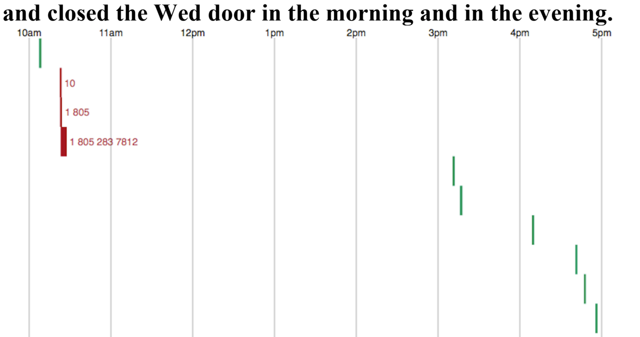

Figure 4. Detailed view of phone calls on a particular day, showing how the user misdialed twice and successfully dialed the number on the third try. The width of the bar represents the length of the call. Red indicates a misdialed number.

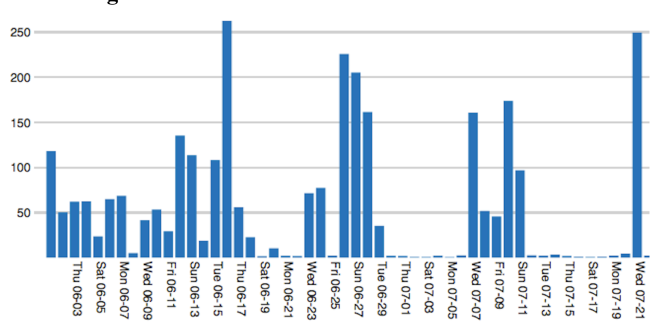

Figure 5. Long-term visualization showing the total number of minutes spent on the phone for each day.

Data Visualizations

For both pill taking and phone use, a high-level, long term view showing performance over weeks or months and a low-level, short term view showing the specific details about the task performance for one day were available.

For pill taking, the long-term visualization (Figure 2) showed the date and time of every instance when a pillbox door was opened over a user-configurable time span of a week to multiple months. Each mark's color represents whether the door was left open until the next pill taking episode (yellow) and whether the pillbox door's label matched (green) or did not match (red) the current day of the week. The green color represents the most typical "correct" sequence of pill taking, that is, opening the correct pillbox door and closing it within a reasonable amount of time, before opening another one. Dots from multiple door openings can overlap and appear in darker shades. A grayed out column represents a day that we were not able to collect data due to a system problem. The short-term visualization (Figure 3) showed how the pillbox doors were opened (dark shading) throughout a particular day.

For phone use, the long-term visualization showed the date and time of every outgoing phone call over a user-configurable time span of a week to multiple months. Each mark was colored green if the call was not misdialed and colored red if misdialed. The metric we used for marking whether a call was misdialed was if two numbers were dialed within a minute of each other and also had 70% of the digits in the first number overlap with the digits in the second number. In the short-term visualization (Figure 4), we showed them the time, length, and number of every phone call made on a particular day. Another long-term visualization of phone use (Figure 5) included the total number of minutes spent on the phone for each day over the course of a week or a few months.

RESULTS

In this section, we describe how the participants both engaged with the data by investigating it and how they reacted to the data with respect to changes in their awareness or intention to change their behaviors.

Engaging with Embedded Assessment Data

Based on the interactions with the visualizations of the task performance data we showed to the participants, we observed how they engaged with the data, what they paid the most attention to, and what other information they wanted to help interpret the data. Participants engaged in three different behaviors: looking for their mistakes in the data, investigating and attempting to explain away these mistakes, and diving down into the details of their task performance to verify their explanations.

Looking for Anomalies/Mistakes

When presented with the visualizations of the data, participants attempted to find any mistakes or anomalies in their own behavior. For example, in the visualizations depicting the states of the pillbox doors on a given day, participants would point out the door states that did not seem normal given that day or that time of day. For example, when P1 first saw the pillbox door state visualization that showed how she opened the pillbox at 7:30pm, she immediately mentioned how it showed her that she took her pills later than usual.

The visualization (Figure 2) that showed long-term pill-taking performance for a week or more highlighted only positive examples of pill taking. The graph contains a dot for every instance a pillbox door was opened. It did not contain, for example, a marking to show when the pillbox was not opened that day. The only visual indication of a missed day is the rather inconspicuous between-dot whitespace, which can be difficult to see especially because the dots do not line up closely with each other. Nonetheless, we observed that P1 and P2 did not focus on the positive examples of pill-taking but rather went to the effort of going through the whitespaces on the graph and seeing if they lined up with a particular day to find instances of missed pills. When first seeing this graph, P2 moved closer to the screen and she said,

"I'm trying to see how quickly I can tell if I missed anything. And to be honest, I have to set [sic] here and study it to see if I did."

Then she used her finger to move along a couple of days to see if a dot lined up vertically with that day. Then she noticed the block of days in the middle of the previous month with no dots, and lamented about her pill taking,

"[There are] a heck of a lot of mistakes on that graph. There're things goin' on that shouldn't be goin' on."

Generating Explanations

After identifying the anomalies in their performance in the data (such as missed pills, opening the pillbox doors incorrectly, or unusually long phone calls), participants immediately tried to think of reasons why the anomalies might have occurred. Finding a reasonable explanation, other than they made a mistake, was important for the participants to know whether they were having a problem or not. Participants used a number of information sources in addition to the pill-taking and phone use visualizations including their memory, routines, and a wall calendar.

Explaining with Personal Memory

Our participants' first natural reaction to seeing an anomaly in the data was to think back to the events of that particular day or week to find an extenuating circumstance to explain the unusual behavior. P1 was particularly good at remembering recent significant events that helped to explain anomalies in her pill taking. For example, upon noticing that many of the pillbox doors were opened out of sequence a few days earlier, she recalled that she received a new supply of heart medication and was placing them into her pillbox to fill out rest the week. In contrast, P2 was less able to recall the details of recent events. When the sensor data showed that she did not interact with the pillbox three days ago, she tried to recall what she did that day that might have explained this error. She said,

"I'm trying to think…I don't remember what I did. I tell you the truth, ever since I've had this problem with my memory, I can't remember that day at all."

P2 had difficulty remembering even recent events as a result of her Parkinson's disease. However, this problem was not isolated to P2 with her Parkinson's, but P1's difficulty in recalling events from the more distant timeframe of a couple of weeks ago also made it difficult for her to explain some apparent instances of missed pills. For example, when thinking back to a weekend three weeks prior, P1 tried to recall whether she was out of town or not. She said,

"I don't think I was away. [thinks hard for a few seconds] I wonder if I was at [my daughter's], but I'm trying to remember."

Then she thought about another instance of when she visited a friend for one night but disqualified that as a valid explanation because that visit happened during the middle of the week. Ultimately, she did not remember what happened on that weekend unassisted, but rather she went to review her wall calendar (discussed in a later section) for some cues for her memory. Even though P1 was able to recall recent experiences adequately, both P1 and P2 eventually had difficulty relying solely on their memory to recall the personal experiences important for explaining anomalies in their behaviors and had to resort to other means such as their routines.

Explaining with Routines

Without an explicit recollection of an event or circumstance that would explain why an anomaly such as a missed pill or a misdialed telephone call might have occurred, participants thought about their routines and whether the anomaly might fit within one of their many variations on their routines. For example, when noticing a few instances of taking her morning pills much later (at 9am) than she normally would have (7am), P1 reasoned that she must have slept in on those mornings. Likewise, when she noticed an instance when she opened up all the doors late on a Friday evening. To explain this anomaly, she drew on two different variations on her routines. She routinely fills her pillbox on a Saturday, but she occasionally refills the box on a Friday and this must have been what happened in this case. To explain why it was so late in the evening, she mentioned that she sometimes goes downstairs to play cards on Fridays and does not return home until after 9pm.

"I can understand that because sometimes on Fridays, not too often, I put [the pills] in for the following week. And that would be in the evening when I come back up from downstairs from what I was doing."

P2 was less able to draw on specific memories of events that might explain anomalies in her pill taking. When noticing in the data that she took her pills very late at night only two days ago, P2 reflected on one of her routine behaviors that she often falls asleep on the couch during the evening which accounts for the lateness of the pill taking.

"I fall asleep, like instantly, if I sit down and even if I'm talking to you, I'll fall asleep, and then I wake up three hours later and know now it's time for my bedtime pills and I'm going to take my pills different[ly]."

Routines and their subtle variations can provide the context to explain away anomalies in task performance data.

Explaining with the Calendar

When unsuccessful in finding either a specific circumstance or routine to explain an anomaly in the task performance, P1 referred to her calendar for hints about what happened on the day(s) of the anomaly. The most common explanation P1 used to explain days with no pillbox activity was that she was away from her apartment which she often recorded on her wall calendar. For example, P1 went to stay with her daughter for a few days in the second month of the study. For that episode, she prepared her medications and placed them in her travel pillbox that she took with her. Naturally, the pillbox instrumented for the study stayed in the apartment and sent signals indicating no activity for those days. While attempting to explain why there was no pillbox activity for that weekend, she noticed that her grandson's name was written in her calendar for that weekend and realized that he was returning from the Army and was home for a visit. Reminded of the details, she said,

"That's right, I went to [my daughter's], [my grandson] took me home with him and we had our get-together that Sunday, and I returned on Tuesday because she was working in town."

Similarly, to explain a couple of misdialed phone calls to numbers that she did not recognize, P1 wondered whom she might have been trying to call that day. She glanced at her calendar and saw a note to herself to call the senior-accessible transit organization to schedule a ride and reasoned that she was trying to call them but became frustrated at the misdialing and used the speed dial on her mobile phone instead. P2, on the other hand, did not keep her appointments on a calendar and struggled to recall what she did on particular days and had more difficulties when trying to explain anomalies. Date-specific information about circumstances from a calendar can help explain date-specific anomalies in the data.

Confirming with Details

Our sensing system could capture task performance at a fairly fine level of detail (*e.g.*, the specific time that a particular pillbox door was opened and every digit dialed for a particular phone call). We presented both a long-term view of the data usually spanning weeks or months and also allowed the participants to review the specific details of each phone or pill-taking episode in a given day. Both participants were able to understand the detailed information after it was explained by the researcher, but they expressed different interest in the detailed information. P1 was interested in knowing the details of when each pillbox door was opened and closed to make sure that she took her pill that day. She also used the details to confirm her explanations. For example, to explain why the log showed that she did not take her medications on Friday night, she remembered that she went to her nephew's party that evening and took her pills with her. She looked at the details of her pillbox interactions that day and saw that it took her 20 seconds in the morning, much longer than normal because she was moving her evening pills into her travel container. P1 also used the detailed data about what phone numbers were dialed in a particular episode of misdialing to explain that she was trying to dial her bank and that it was common for her to make mistakes with all those numbers and would have to restart the call often. In P1's case, she was able to use the detailed information collected about the tasks she performed along with knowledge of her recent events and habits to understand why anomalies occurred.

In contrast, the detailed information was less helpful for P2 for generating explanations because even though she understood the details, she could not think of the context of that interaction to explain why particular doors were opened at that time or why a particular phone call was so long. As a result, P2 was repeatedly baffled by the details the sensors recorded which challenged her self-awareness of her behaviors. With a perplexed look on her face, she said,

"I can't imagine why I would open it that way. Looking at an individual day isn't all that helpful because I don't remember what I did that day."

The value of providing low-level details of task performance to users for reflection depends on their ability to use the details to recall the context and explain their behavior.

Reactions to the Data

In addition to observing how the individuals reflected on the data and made sense of it to themselves, we found that the sensor data about their everyday performance provided the ground truth by which they could reaffirm or gain an accurate awareness of their functional abilities. After realizing the inconsistency in their routines through exploring the data, both individuals intended to "do something about it" and be more consistent to ensure safety. The participants also expressed opinions about sharing the information with members of their care network. In the following sections, we describe these themes in detail.

Supporting Accurate Awareness

Awareness of changes in functional abilities is key for successful aging, as it provides opportunities for the individual to make the appropriate adaptations to ensure she remains functional and avoid situations that threaten her safety [6]. Prior to viewing any of the sensor data, both participants P1 and P2 were confident that they performed their pill taking regularly and almost never missed their medications. P1 expressed, “I do feel confident that I always take my medications, but hopefully it will continue a few more years.” P2 also expressed her confidence that she never missed her medications because “I’m afraid if I don’t take them, I’ll regress and my Parkinson’s will start again.”

However, P1 and P2 differ in the accuracy of their confidence in their pill taking routine. P1’s confidence in her routine actually matches her functional abilities. She believes that she almost never missed a pill and over the four months that we monitored her pill taking, she never missed a day without opening the pillbox at least once when she was home. However, P2’s pill taking routine is more erratic, showing instances of isolated days where she did not open the pillbox at all or opened up a pillbox door that did not match the day of the week. As a result, the sensor data had very different impacts on P1 and P2.

For P1, the data provided a means to affirm her accurate confidence in her pill taking, whereas for P2 the data was useful for re-assessing her own (over-)confidence in her pill taking routine. When seeing that there was a green dot almost every day indicating that she opened the correct pillbox door, P1 said

“I always feel confident that I take my medications and [the data] helps me confirm that I’ve taken my medicines.”

She also commented that even the gaps in her pill taking shown in the data was helpful because

“I see in front of me what I do, and as long as I can confirm in my mind that I’ve taken my medication, that’s good.”

Even though P1’s awareness of her abilities was relatively accurate, she was initially surprised at the variability of when she took her pills during the day and how often she misdialed the telephone. Her feelings of surprise quickly transitioned to acknowledgement, as she was able to explain the variability and the number of misdials by accounting for them in natural variations in her routines, as described in the Generating Explanations section above.

P2, on the other hand, had her confidence challenged when she saw the inconsistency and variability in her pill taking data. For example, when seeing in the data that she tended to take her morning pills anywhere between 10am and noon, she said,

“I thought I took my pills around 9:30am because I sleep late. No longer do I rise at 7am, but I never thought of it.”

When seeing many gaps in her pill taking data, she remarked about her own prior confidence,

“You actually physically know that you took it that day, but no, you didn’t. I hate to acknowledge that; it’s just another thing that I don’t want happening.”

During the interview session, P2’s awareness went through a transformation from being absolutely (but falsely) confident in her abilities to feeling a little shaken that she might not be as aware as she thought she was. She expressed,

“Being able to see it right in front of you, the bad things, is amazing to me. Gawd! It’s making me feel really screwed up. I wouldn’t have thought I did that.”

Adding to P2’s frustration was her inability to think of specific reasons why she might not have opened her pillbox on particular days or why she opened the pillbox doors in a strange way. At the end of the interview after she saw all the data, her prior confidence changed to concern, she said,

“I have to admit, you’re not aware of the mishaps you do. You have no idea you’re doing some of those dumb things you see other people do. It’s just a fact of life.”

Despite their different emotional outcomes, both P1 and P2 were able to use the objective and timely data collected from the sensors as “ground truth” to evaluate their own confidence in their functional abilities.

Intention to be More Consistent

Based on a newly gained awareness of their abilities to take the right pills at the right time and correctly make telephone calls, the participants resolved to be more consistent in their routines to ensure their safety and adherence to their medications.

P1, despite her relatively accurate awareness of her pill taking routine, decided she wanted to be more consistent in what time of day she takes her pills. A more consistent routine would make her feel more confident that she took them and would help her to ingrain in her brain a successful habit that will last into the future. Talking about how she will continue with her routine to move her pills from the box to the visible bowl on her counter, she said “I have to get more consistent in opening that box and putting them in [the bowl]. See, I’m so used to that routine. I keep that little black bowl on my counter for that reason.” After seeing how often she was misdialing the phone, she said she wanted to buy a new phone with buttons that are easier to press so that she can be more consistent in her phone dialing and figure out whether the problem was caused by her old phone or her old arthritic fingers.

P2, after seeing the large variability and the unexplainable instances of missed pills, resolved to be more consistent and to pay more attention to her pill taking. She equated her poor pill taking performance with "messing with [her] life" because she currently is taking a "miracle" drug for Parkinson's disease and she certainly does not want to regress to a point where the Parkinson's symptoms re-emerge. She said, "I'm gonna set a time for me for my pills and try to adhere to that, say at the 11 o'clock news." She even began to question her evening medication taking routine (which is not monitored by our pillbox because her evening pillbox is a different type) and whether she was taking that properly. She considered whether or not to keep a written diary where she would check off everyday whether she performed important tasks like taking her pills.

Desire to Share Data and Potential for Misinterpretation

Both participants wanted to share their information with their family members so that others could know how well they are able to remain independent. P2 said her daughters, particularly the one who is a nurse, would want to see the data and help her mother fix any problems that might come up. Similar to previous findings [3], participants wanted to keep their information private to just their own family, close friends/helpers, and their doctors.

With sharing comes the additional risk for misinterpretation. P1 was concerned that others who would look at the data might not be able to determine whether the anomalies in the data (*e.g.*, missed or late pills or misdialed telephone) are benign or a cause for concern. She is able to look at the graphs and figure out whether the apparent missed pills are explained by being out of town or taken in some other acceptable way. She often talked about "confusing the poor little pillbox" when she does something that is not typical of routine. She explained, "I know what I'm doing, but the interpreter doesn't know why I haven't been consistent in opening the boxes right."

Data about Everyday Activities Useful as Memory Cue

Many older adults (as well as younger adults) struggle with recalling the details of events on particular dates. P1 explains how her memory is important to her:

"I worry about being able to remember things and like Sunday evening when I go to bed, I try to give myself a test to see if I can remember what I did all week, sometimes I can easily where something sparks in my head about what happened Sunday and everything comes back."

Time or a date is a typically poor memory cue [5]. Often calendars (electronic or paper) can be a good source of memory cues. However, not all events are typically recorded on a calendar. P1 found the automatically generated log of her pill taking and phone use to provide good cues to help her remember her recent summer activities. As she was explaining away the days for which she did not open a pillbox door, she fondly reminisced about the many times she travelled to her daughter's, had a visit from her grandson, and went to stay with a friend. She said, "this is good because it makes me think about some of the things I did this summer." When looking at the length of phone calls for each day of the previous month, she was reminded of when she had a long talk with a friend who was sick. P1 was able to use the sensor data, as well as her own memory and calendar, to do some "mental time travel" by mentally reliving recent events. In contrast, P2 was unable to use the sensor data to cue into her memory because she just did not remember the details of recent events at all.

DISCUSSION

From our interview case studies, we observed how the two older adults engaged with the data about how well they took their medications and used the telephone, two everyday tasks important for independence and aging in place. As more research and commercial systems for home health monitoring are being developed and marketed for older adults, the demand for principles for maximizing the usefulness and usability of these systems becomes clear. In this section, we first discuss the value these systems had for our participants and other older adults like them. Then we describe recommendations for how to improve the design of home sensing systems for older adults.

Value of Embedded Assessment for Older Adults

One of the benefits of embedded assessment proposed in [18] was that it provides objective data about performance of behavior to complement the subjective accounts from self-report and caregiver reports for older adults. We saw in our case studies that both individuals were able to use the automatically collected data about their behaviors to test their awareness of their functional abilities. When the participants were unable to explain an anomaly (*e.g.*, missed pill or misdialed phone number) in the data, they trusted that the system recorded it correctly and became aware of their mistake. The data also enabled them to reflect on not just the recent past but also on their behaviors months earlier, allowing them to see if isolated behaviors were actually more common than they realized and thus cause for concern. Thus, presenting embedded assessment data can support self-reflection, resulting in greater and more accurate awareness for older adults, a benefit both for individuals who have an accurate perception of their abilities (as in the case with P1) as well as for those whose perception is less congruent with their actual behavior (as in the case with P2). In addition to providing an objective account of their actions for supporting awareness, the embedded assessment data provided them with both the trigger as well as the specific information necessary to make adaptations to ensure their independence and safety.

An unexpected value of the embedded assessment data that we identified in this study is they can be used to support everyday reminiscence of activities and events unrelated to the particular tasks monitored much like richer cues such as photos and messages [20]. The data provides a window into the pattern of activities that active older adults perform. Deviations from the normal pattern can signify a non-routine event that may not normally be salient enough (but nonetheless meaningful and personally significant) to recall without a cue. Data about tasks around the home can provide cues for special events that older adults (and indeed younger adults) want to be able to recollect and mentally re-experience in their minds.

Design Recommendations

Based on our observations of how the older adults in our case studies explored and used the information to make sense of and reflect on their own functional abilities, we provide recommendations for designing home sensing systems that support self-reflection for older adults.

We observed that users were eager to not just look at the visualizations at a glance but actually spent the time to study them to find instances where it looked like they made a mistake. Similar to the process of finding key events in data used in intelligence analysis [4], users looked for anomalies. However, in contrast to intelligence analysis, which requires a high amount of interpretation by the analyst, anomalies in task performance can be more easily identified computationally. Thus, we recommend from a usability standpoint that *the instances of anomalous behaviors likely to be caused by the user should be highlighted or at least represented in a way that requires minimal analysis by the user*. As a negative example, the multi-month visualization (Figure 2) for pill taking only included marks where the pillbox was opened, relegating the representations of missed pills to narrow, difficult-to-notice columns of white space.

The contrasting outcomes between our two participants highlight the need for supporting better explanations of anomalous behaviors. Many older adults have difficulty remembering their recent experiences due to either neurological conditions (like P2) or simply benign declines in memory associated with aging (like P1). To be able to identify whether an anomalous behavior is acceptable or a mistake, the context of the behavior needs to be available. Thus, designers of embedded assessment systems should *provide tools to allow the user to retrieve the context of the data such as special events from calendars, people encountered that day, or to-do lists in addition to just presenting the data by itself*.

In addition to providing context for explanation, *providing the low-level details of the behavior can support a better understanding, explanation, and fixing of the behavior*. For example, seeing that a particularly long telephone number is being misdialed helps the user to understand they might have a problem with digit span memory and have to pay attention more when dialing that number. We also found that there was little demand to see the details of behaviors that were judged as "good" (such as correctly dialed phone calls or days where pills were taken). Thus designers, if faced with a shortage of resources, can focus on providing the details for the anomalous cases. For example, when a system is able to detect an anomaly in near real time, the system can increase the resolution of sampling at the cost of a temporary increase in battery or memory consumption.

The value of embedded assessment data extends beyond the individual monitored to other members in their care network such as relatives and clinicians. The users in our case studies suggested that the information be shared with their relatives so they can look after them more closely. However, users were concerned that others might misinterpret their seemingly errorful but explainable behaviors as mistakes. Therefore, designers should *allow for collaborative sharing and exploration of behavioral data or support annotation of the data before sharing with others to avoid misinterpretations*.

Study Limitations

Our case study approach provided us with a rich understanding of how our participants engaged with the data and found the data useful for building or reinforcing their awareness of their functional abilities. We acknowledge that not all older adults are similar to our participants. However, the case studies were most useful for comparing and analyzing the similarities and differences between two very different older adults, each representing a different end of the spectrum in their abilities to remain aware of their functional abilities. Even though P1, a successfully aging older adult, and P2, a struggling, less aware older adult are very different, they both benefited from the objectivity and timeliness of embedded assessment data. Also, the scope of our data collection was limited to two tasks. However, the pill taking and phone use tasks have been standardized as part of the normal battery of tasks used for functional assessments [11] and thus are likely to be most sensitive for indicating changes in cognitive and functional abilities. Furthermore, the sensors may collect false data, particularly if users purposely game the system. Our future work includes developing a suite of other task-based sensors that can monitor sleep, sitting, meal preparation, and coffee making. These sensors will monitor the entire process of the task such as from the first step of opening the pillbox to the near final step getting water from the tap to take with the pills. This study also used only researcher-designed visualizations as probes. The results from this study can serve as the first round of user-centered iterative refinement of the visualizations.

CONCLUSION AND FUTURE WORK

In this paper, we discussed how we designed and deployed a prototype home sensing system that collected four months of data about how two different older adults performed two tasks important for successfully aging in place, pill taking and phone use. We presented two case studies of how two older adults (one aging successfully and managing her awareness well, and another who struggles with maintaining consistency and awareness of her abilities) investigate their data and how they used the data to adjust or reaffirm their awareness of their functional abilities.

We found that our participants looked for and focused on anomalies in the data (*e.g.*, missed pills or misdialed phone calls) that may indicate a mistake that might be their fault. They tried their best to explain away the anomaly by thinking of an event, circumstance, or reason why that anomaly might actually be acceptable. They drew first on their own memory of events to find an explanation. Often lacking a specific explanation from their declining memories, the older adults drew next on their routines in an attempt to make the anomaly acceptable by placing it within one of their routines. They then consulted other sources of date-specific information such as calendars and diaries if they were available. Designers can support this investigation process by clearly marking the anomalies and can support the explanation process by providing the date-specific context that gives hints as to what activities might have occurred on particular days.

We also were able to validate one of most important potential benefits of embedded assessment data—that it helps older adults with managing their awareness of their functional abilities. We found that the objective data collected on her task performance allowed an older adult to adjust her inaccurate awareness of her functional abilities as well as for another older adult to affirm her accurate awareness of her abilities. As a result, they were empowered to make the appropriate adaptations to be more consistent and aware of their pill taking and phone use to safeguard their independence. Furthermore, to avoid misinterpretation when sharing performance data, designers should support joint viewing or at least allow the older adult to annotate and explain their performance.

In future work, we plan to continue monitoring our two participants as well as to include other adults with different levels of awareness and abilities. Home sensing systems have the ability to monitor behaviors seamlessly and over a very long term, and thus we plan to investigate how older adults and other stakeholders including caregivers and doctors engage with much longer-term data such as over years instead of months.

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REFERENCES

1. Ballegaard, S., Hansen, T. and Kyng, M. Healthcare in everyday life: designing healthcare services for daily life. *Proc. CHI 2008*, ACM Press (2008), 1807–1816.
2. Bamis, A., Lymberopoulos, D., Teixeira, T., and Savvides, A. Towards precision monitoring of elders for providing assistive services, *Proc .PETRA*, (2008), 49-56.
3. Birnholtz J. and Jones-Rounds, M. Independence and interaction: understanding seniors' privacy and awareness needs for aging in place. *Proc. CHI*, ACM Press (2010), 143-152.
4. Chin, G., Kuchar, O.A., and Wolf, K.E. Exploring the analytical processes of intelligence analysts. P*roc. CHI 2009*, ACM Press (2009), 11-20.
5. Dijkstra, K. and Misirlisoy, M. Event components in autobiographical memories. *Memory*, 14(7), (2006) 846–852.
6. Fried, L., Herdman, S., Kuhn, K., Rubin, G. and Turano, K. Preclinical disability: hypotheses about the bottom of the iceberg. *Journal of Aging and Health*. 3(2), (1991) 285-300.
7. Glaser, B.G. and Strauss, A.L. *The discovery of grounded theory: Strategies for qualitative research*, Aldine (1967).
8. Hayes, T., Hunt, J., Adami, A. and Kaye, J. An electronic pillbox for continuous monitoring of medication adherence. *Proc. EMBS*, (2006), 6400-3.
9. Hilton, K., Fricke, J. and Unsworth, C. A comparison of self-report versus observation of performance using the ALSAR with an older population. *The British Journal of Occupational Therapy*, 64(3), (2001), 135–143.
10. Kaye, J. Home-based technologies: A new paradigm for conducting dementia prevention trials. *Alzheimer's & Dementia*, 4(1), (2008), S60–66.
11. Lawton, M.P. and Brody, E.M. Assessment of older people: self-maintaining and instrumental activities of daily living. *The Gerontologist*, 9(3), (1969), 179-187.
12. Leifer, B.P. Early diagnosis of Alzheimer's disease: clinical and economic benefits. *Journal of the American Geriatrics Society*. 51(5), (2003), S281–288.
13. Li, I., Dey, A., and Forlizzi, J. A stage-based model of personal informatics systems. *Proc. CHI 2010*, ACM Press (2010), 557–566.
14. Maitland, J. and Chalmers, M. Self-monitoring, self-awareness, and self-determination in cardiac rehabilitation. *Proc. CHI 2010*, ACM Press (2010), 1213-1222.
15. Mamykina, L., Mynatt, E., Davidson, P. and Greenblatt, D. MAHI: investigation of social scaffolding for reflective thinking in diabetes management. *Proc. CHI 2008*, ACM Press (2008), 477–486.
16. Mihailidis, A., Boger, J., Canido, M. and Hoey, J. The use of an intelligent prompting system for people with dementia. *Interactions*, 14(4), (2007), 34-37.
17. Morris, M. and Intille, S. HCI challenges in health assessment. *Extended Abstracts CHI 2005*. ACM Press, (2005), 2130-1.
18. Morris, M., Intille, S. and Beaudin, J. Embedded assessment: Overcoming barriers to early detection with pervasive computing. *Pervasive Computing*, (2005), 333–346.
19. Okonkwo, O. *et al.*, Awareness of Functional Difficulties in Mild Cognitive Impairment: A Multidomain Assessment Approach. *Journal of the American Geriatrics Society*. 57(6), (2009), 978–984.
20. Peesapati, S., Schwanda, V., Schultz, J., Lepage, M., Jeong, S. and Cosley, D. Pensieve: supporting everyday reminiscence. *Proc. CHI 2010*, ACM Press, (2010), 2027-2036.
21. Rantz, M. *et al.*, TigerPlace: an innovative educational and research environment, *AAAI in Eldercare: New Solutions to Old Problems*, Washington DC, 2008.
22. Saxton, J., Morrow, L., Eschman, A., Archer, G., Luther, J. and Zuccolotto, A. Computer assessment of mild cognitive impairment. *Postgraduate Medicine*, 121(2), (2009), 177-185.
23. Tapia, E., Intille, S., and Larson, K. Activity recognition in the home using simple and ubiquitous sensors. *Pervasive Computing*, (2004), 158–175.
24. Willis, S. Everyday cognitive competence in elderly persons: Conceptual issues and empirical findings. *The Gerontologist*. 36(5), (1996), 595-601.